GEOCHEMICAL AND GEOCHRONOLOGICAL STUDY OF THE DANBURG AND SANDY HILL GRANITOIDS AND ASSOCIATED MAFIC ENCLAVES,

NORTHEAST GEORGIA

by

DOUGLAS K. DVORACEK

(Under the Direction of Michael F. Roden)

ABSTRACT

A comprehensive data set of whole rock and mineral chemistry has been collected from the Alleghanian Danburg pluton and associated igneous rocks. The pluton has been dated at 304 +/- 5 Ma, with an initial Sr ratio of 0.70476 +/- 0.00016. Amphibole-plagioclase thermobarometry indicates the early magma crystallized at pressures and temperatures similar to nearby Alleghanian granites.

Mafic enclaves in the Danburg pluton are shown to result from quenching of an intermediate or gabbroic magma that likely had peralkaline affinities. These unusual compositions produced texturally rare enclaves with high HFSE contents and abundant titanite. The proximity of a syenitic stock adjacent to the Danburg pluton suggests that this magma may be the source of the mafic enclave magma.

The Danburg pluton is an LIL-enriched body with trace element chemistry similar to subduction related magmas. However, overall geochemical, isotopic, and field relations favor a post-subduction environment for magma genesis. It is therefore proposed that the Danburg pluton formed after the cessation of subduction, possibly in response to crustal thickening or intrusion of more mafic magma into the crust following the collision of Laurentia and Gondwana. Geochemical signatures suggestive of subduction regimes are likely inherited from the source area.

The Sandy Hill pluton is a leucocratic envelope on the south and southeastern margin of the Danburg body. Whole rock and mineral chemistry, coupled with isotopic data, indicate that the Sandy Hill pluton is an approximately contemporaneous intrusion but is not genetically related to magma that produced the Danburg pluton.

INDEX WORDS: Alleghanian, Geochronology, Granite, Mafic enclave, Magma mixing, Southern Appalachians

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CHAPTER I: INTRODUCTION

The Alleghanian orogeny affected the present-day east coast of North America between approximately 270 to 320 Ma. One of the main surface expressions of this event is an arcuate belt of undeformed granitic plutons, which stretches from Nova Scotia to Alabama. Several of these plutons were dated in the latter part of the last century by Rb-Sr methods. There is general agreement that they are approximately 300 Ma old, but recent high precision U-Pb data have called their precise ages into question.

The Alleghanian plutons were long considered to have formed above a subduction zone (e.g. Sinha and Zietz, 1982: Sinha et al., 1989). This interpretation was likely influenced by the overall arcuate distribution of the present day exposures, and for many years the main debate concerned the polarity of the subduction zone.

In more recent years, detailed chemical studies have called into question exactly how important subduction was to the generation of the Alleghanian plutons (e.g. Vyhnal et al., 1991 ; Samson et al, 1995; Speer et al., 1994). Several lines of evidence are used to argue against these magmas being generated by subduction zone processes. These are discussed below, in a summary of the current thinking concerning the specific tectonic setting in which the Danburg and similar plutons were emplaced.

Summary of Alleghanian tectonic environment

The type and extent of subduction during interaction of Laurentia and Gondwana is unresolved. Stratigraphic and geochronologic studies (Thomas and Mack, 1982; Mack et al., 1983; Secor et al., 1986; Dallmeyer et al., 1986) demonstrate metamorphism, deformation, and plutonism on the eastern margin of Laurentia to be coeval with the formation and deformation of Alleghanian foreland basins, where clastic sedimentation had begun by approximately 325 Ma. Sinha and Zeitz (1982) argue from K₂O, SiO₂, δ^{18} O trends and Sr initial ratios and abundances that Gondwana was subducted westward under Laurentia, resulting in a magmatic arc represented by the Alleghanian plutons. They time the initiation of subduction at approximately 330 Ma. Sacks and Secor (1990) argue for south to south-southeast subduction of Laurentia under Gondwana, based in part on the absence of late Paleozoic arc-volcanic rocks on the south margin of Laurentia. In the crystalline terranes, interaction between Laurentia and Gondwana is recorded in the Kiokee belt, approximately 35 km southeast of the Danburg pluton, between 315-295 Ma (Secor et al., 1986; Dallmeyer et al., 1986). This was accompanied by oblique normal slip in the SW-dipping Modoc zone (Sacks and Dennis, 1987). Dennis et al. (1987) show that the strike extension of the Modoc zone (the Irmo zone) was reactivated between 291-268 Ma as a strike slip system, arguing that lateral displacement was in response to late-Alleghanian adjustment to collisional forces, and not indicative of an overall transpressive regime. However, Gates et al. (1988) argue that these and other strike-slip fault systems formed as part of a mega-duplex, where collisional forces were largely resolved into a series of anastomosing strike-slip fault systems forming a contractual, transpressional orogen.

On the basis of new and compiled major element data coupled with new Nd, Pb and Sr isotope data, Samson et al. (1995) argue that the overwhelming majority of Alleghanian plutons were generated from sources with no connection to subduction regimes. Particularly, Nd and Pb data from Carolina terrane rocks are very similar to the same data from Alleghanian plutons intruding the Carolina terrane, indicating that the Alleghanian plutons most likely intrude higher crustal levels of their own source rocks. Their data also show that the Nd and Pb isotopic composition of average 300 Ma mantle is significantly different from the Alleghanian plutons. Therefore, Samson et al. (1995) argue for a decompressional or delamination origin of the plutons, but cannot eliminate a crustal thickening origin. Sacks and Secor (1990) suggested that lithospheric delamination of a portion of the subducted Laurentian margin juxtaposed hot mantle asthenosphere with cold lower crust, providing the heat necessary for metamorphism and plutonism. Nelson (1992) bolstered this argument by noting that seismic profiling indicates crustal thickness decreases from the foreland to the internides, a geometry typical of some collisional orogens and attributed to delamination subsequent to collapse of the orogen

The models outlined above should lead to different mechanisms by which plutons are generated. Both delamination and transpressional arching result in rapid uplift of the crust. Decompressional melting of the asthenosphere will then emplace basalt into the lower crust and facilitate melting. Delamination, by also placing hot asthenosphere directly against lower crust, should provide a more efficient melting mechanism than simple crustal arching. Subduction-related magmas, and those arising from crustal thickening, should also preserve geochemical signatures characteristic of each process. Speer et al. (1994) concluded that geographic-compositional-temporal trends were insufficient to support a subduction origin for the plutons. They favored a deformationdriven mechanism for magma generation, suggesting some combination of juxtaposition of hot asthenosphere against the lower crust, decompressional melting and volatile influx. Samson et al. (1995) also argued against a subduction origin, citing insufficient geochemical trends and isotopic evidence consistent with crustal anatexis. Speer and Hoff (1997) compiled major and trace element data from 42 of the 60 plutons considered to be Alleghanian, adding 34 new analyses from 13 of the plutons. This data was inconclusive when plotted on tectonic discrimination diagrams, suggesting the plutons were emplaced in a destructive marginal setting during or subsequent to continent - continent collision, possibly during a time of transition between broad tectonic environments.

The major focus of this study is to determine the origin of the mafic enclave suite in the Danburg pluton. As these are unusual enclaves rarely noted in the literature, the Danburg pluton itself is somewhat petrologically unique, and thus differs from many of the Alleghanian plutons in the region. The enclave suite likely records a segment of the early history of the pluton that is not preserved elsewhere. These data, coupled with precise geochronology and a comprehensive study of the major and trace element chemistry of the pluton, should enable a better evaluation of the Alleghanian environment in this portion of the orogen.

CHAPTER II: GEOLOGIC SETTING OF THE NORTHEAST GEORGIA PIEDMONT

During the late Precambrian and Paleozoic eras, the southeastern edge of the North American continent grew by accretion and generation of new crust during the Taconic (ca. 435-480 Ma), Acadian (ca. 340-400 Ma), and Alleghanian (ca. 268-315 Ma) orogenies. In Georgia, the Appalachian orogen is divided into a series of northeast trending belts defined on the basis of lithology and metamorphic grade (Figure 2-1). In Georgia, from northwest to southeast, these are the Valley and Ridge, Blue Ridge, Inner Piedmont, Carolina slate belt/Charlotte belt (also known as the Carolina or Avalon terrane), and Kiokee belts (King, 1955; Overstreet and Bell, 1965; Hatcher, 1972). Belts are bounded on both sides by major shear zones, which often record complicated histories and reactivation of older structures. A number of tectonic syntheses have been developed incorporating stratigraphy, structural studies, and geochronology into coherent models explaining the growth of the Appalachian orogen (e.g. Hatcher, 1972, 1978, 1987; Odom and Fullagar, 1973: Glover and Sinha, 1973: Rankin, 1975: Hatcher and Odom, 1980; Williams and Hatcher, 1982, 1983: Higgins et al, 1984; Sinha et al, 1989). These models generally agree that in Georgia, the orogen consists of folded miogeoclinal sediments (Valley and Ridge), an oceanic segment developed in part on North American crust (Blue Ridge), suspect (North American ?) crust (eastern Blue Ridge and Inner Piedmont) which may represent a slope-rise assemblage deposited offshore from the North American craton, and an exotic microcontinental block of probable island arc affinity (Carolina terrane). An attached block of African crust is believed to be present in the subsurface below the Coastal Plain, but is nowhere exposed (Hatcher, 1987, and references therein).

One critical yet poorly resolved relationship in Georgia concerns the timing of the accretion of the Carolina terrane to the Inner Piedmont. The origin of the Inner Piedmont

remains suspect in this portion of the orogen, primarily because of tenuous correlations with known lithologic groups, and because of the presence of a strong horizontal reflector beneath the terrane, interpreted as a major detatchment (Williams and Hatcher, 1982; Cook et al, 1979; Rankin, 1975). In contrast, the Carolina terrane has been definitively shown to have formed somewhere not proximal to North America (Secor et al, 1983; Williams and Hatcher, 1982, 1983; Neuman et al, 1989). In north central Georgia, the boundary between these terranes is defined by Hooper and Hatcher (1986, 1990) as the Ocmulgee fault zone. They interpret the fault zone to have formed during oblique dextral convergence of the Carolina terrane and the Inner Piedmont, and believe the fault boundary extends along strike to the northeast, continuing as the Middleton-Lowndesville zone. The Middleton-Lowndesville zone, in turn, is believed to be correlative with the Kings Mountain belt in South Carolina. Protolith ages of Carolina terrane metaigneous rocks adjacent to the Danburg pluton suggest the terrane is as old as 570 Ma (Dallmeyer et al, 1986), while Samson et. al. (1995) list pluton ages as old as approximately 620 Ma. Hooper and Hatcher (1990) inferred that a steep zone of foliation which developed during the accretion of the Carolina terrane to the Inner Piedmont formed around 350 Ma. This latter age is based on mineral cooling ages and timing criteria between mineral growth and deformation, and thus, is poorly defined. Similarly, Horton (1981) inferred that the most recent deformation in the Kings Mountain belt took place at 352 ± 10 Ma, based on Rb-Sr whole rock ages of pegmatites cutting deformed Kings Mountain belt rocks; some of these pegmatites were deformed, and may therefore represent cooling ages, rather than crystallization ages. Early Paleozoic uplift histories of rocks in this area are poorly known, and hence, the actual accretion age could possibly be much older than that

inferred from cooling ages. Based on the distribution of geochemically coherent plutonic rocks (Sinha et.al., 1989), the paucity of mid-to-late Ordovician plutons in the Carolina Slate belt, Siluro-Devonian pluton ages in the Charlotte belt (Sinha et.al., 1989), and evidence of Pb-loss from zircon systems at nearly 350 Ma (Seiders and Wright, 1977) and 365 Ma (Sinha et.al., 1971), Sinha et.al., (1989) suggested the Carolina terrane was sutured to the Inner Piedmont between 360 - 400 Ma.

Regional Geologic Background

The study area is located in northeast Georgia, within Lincoln and Wilkes counties. Figure 2-2 shows geologic relations in the vicinity of the Danburg and Sandy Hill granitoids. Figure 2-2 was taken from Allard and Whitney (1991), and was simplified by grouping related volcaniclastic units.

The rocks studied here are entirely within the boundaries of the Carolina terrane, whose boundaries are defined by the Modoc zone to the southeast, and the Middleton-Lowndesville fault zone to the northwest. Radiometric age determinations in this immediate area are few in number, thus, cited radiometric ages are in reference to investigations performed along strike in correlative regions outside the study area.

Inner Piedmont and Middleton-Lowndesville Zone

Inner Piedmont lithologies are dominated by paragneiss, with subordinate orthogneiss, schist, and amphibolite. Minor occurrences of calc-silicate are also present. Biotite- or biotite-hornblende gneiss is common, with sillimanite grade conditions recorded in areas of appropriate bulk composition. Inner Piedmont lithologies were believed to have originated largely as slope-rise sediments deposited at an unknown location somewhere offshore of North America (Williams and Hatcher, 1982, 1983; Hatcher, 1987). Other interpretations of the origin of the Inner Piedmont include; one or more volcanic island arcs between the Carolina Terrane and Laurentia (Hatcher, 1987); a melange terrane (Horton et. al., 1989); and as the basement on which the Carolina Terrane accumulated (Dennis, 1991).

Pluton emplacement ages elsewhere in the Inner Piedmont are widely variable. Odom and Fullagar (1973) and Kish and Fullagar (1978) recognized deformed plutons in North Carolina of age about 535 Ma. Kish and Fullagar (1978) report post tectonic plutons near the North Carolina-South Carolina border of approximately 350 Ma. In Georgia, Ross and Bickford (1980) recognized undeformed plutons of about 300 Ma. Recent work has identified Grenville age gneisses (1.0 to 1.3 Ga) and documented substantial Acadian (340-400 Ma) plutonism and metamorphism (Mapes et al., 2001; Bream et. al., 2001).

Metamorphic cooling ages in the Inner Piedmont are equally variable, although such ages are better known near the study area than are pluton crystallization ages. Van Breemen and Dallmeyer (1981) have shown that Rb-Sr systems in the nearby Athens gneiss were closed by 390-400 Ma . Immediately west of the study area, Dallmeyer (1978) reported 236-317 Ma biotite and 300-355 Ma hornblende ⁴⁰Ar/³⁹Ar cooling ages from migmatites and granitic gneisses. In contrast, Harper and Fullagar (1981) suggested that the age of metamorphism in the Inner Piedmont of North Carolina is about 440-475 Ma. Mirante (2001) has dated metamorphic monazites in the area near Athens, Georgia, and rercords peak metamorphic ages of 330 +/- 15 Ma. The disagreement in ages apparently reflects the diachronous nature of plutonism and metamorphism in the region, or perhaps is also related to the questionable significance of Rb-Sr ages of deformed plutons.

Figure 2-1. Lithotectonic map of the Southern Appalachians showing the distribution of Alleghanion intrusive rocks. The Danburg pluton (identification code DB) is outlined in heavy border. From Speer and Hoff, 1997.



Figure 2-2. Geologic map of the area surrounding the Danburg pluton. Geologic relations in the vicinity of the Danburg pluton, located in Lincoln and Wilkes Counties, Georgia; simplified from the compilation map of Allard and Whitney, 1991. The towns of Lincolnton and Washington are added for reference. A lithologic symbol legend is located on the page immediately following the map.



KEY TO SYMBOLS



Danburg granite



ductile deformation zones; Modoc zone to SE Middleton-Lowndesville to NW



Sandy Hill granite



granite-granodiorite suite; Siluro-Devonian(?) highly variable



metadacite; includes Lincolnton metadacite



felsic metapyroclastic sequence with minor interlayered mafics



gabbros and/or subordinate syenite



biotite shist & gneiss; higher grade equiv. to felsic pyroclastic rocks



hbl tonalite

hbl diorite



sericite or sillimanite schists, representing hydrothermally altered tuffs



mafic and intermediate metavolcanic units; chlorite grade to amphibolite

The eastern edge of the Inner Piedmont is defined by a steeply southeast dipping series of mylonitic shear zones termed the Ocmulgee fault zone. Shear sense criteria southwest of the proposed study area indicate that the Ocmulgee fault zone formed during dextral strike slip motion (Hooper and Hatcher, 1986, 1990). Davis (1980), and other M.S. students from the University of Georgia (see Allard and Whitney, 1994, for a comprehensive bibliography of theses), have extended the Ocmulgee fault zone through the study area, where the fault zone is termed the Middleton-Lowndesville zone. Preliminary examination of mylonites in the Middleton-Lowndesville zone shows that in limited areas they also record dextral strike slip motion, although most outcrops record dip-slip movement.

Carolina terrane

The Carolina terrane is distinguished from the Inner Piedmont by differing stratigraphy and, to a lesser extent, metamorphic grade. The Carolina terrane is believed to represent a Precambrian to Cambrian island arc terrane composed of volcanic, volcaniclastic, pyroclastic and sedimentary rocks (Whitney et.al., 1978; Kish and Black, 1982; Secor et.al., 1983). The exotic nature of this terrane was first confirmed by Secor et. al. (1983). Peak metamorphic conditions recorded in the Carolina terrane were long thought to range from greenschist to amphibolite grade. More recent work by Dennis and Wright (1997) and Colbert (2001) has documented substantially higher grade conditions, ranging from 720 °C at 4 kbar to 620-680 °C at 15 kbar. These rocks are intruded by a variety of granitic and gabbroic plutons of variable age. While many plutons in the Carolina terrane are probably of Ordovician age, there is clear evidence of syntectonic plutonism along strike to the northeast, associated with the late Paleozoic Alleghanian orogeny. Additionally, some plutons are clearly post-deformational, and were most likely emplaced near or after the cessation of Alleghanian deformation.

Metamorphic cooling ages in the Carolina terrane are well documented immediately to the northeast of the study area and indicate a widespread 340-360 Ma thermal event recorded by 40 Ar/ 39 Ar whole-rock spectra from slates and phyllites (Dallmeyer et. al., (1986). The authors reported 40 Ar/ 39 Ar ages of hornblendes ranging from approximately 290-340 Ma, and biotite ages ranging from approximately 240-290 Ma, in the same area. Argon release spectra from this study were complicated and discordant, but the authors attributed the variability in ages to diachronous cooling and to excess argon.

It has long been recognized that in the Carolina terrane, pluton ages tended to group into suites of approximately 400 - 460 Ma and 360 - 400 Ma (Fullagar, 1971; Fullagar and Butler, 1979). However, it is important to note that within individual plutons, there is a discrepancy between Rb-Sr whole rock and U-Pb zircon ages; in many cases, differences of 80 Ma are apparent. As many of the Rb-Sr ages were determined from deformed or mylonitic samples (e.g. Butler and Fullagar, 1978; Fullagar, 1971), these ages most likely represent a cooling age of questionable significance to times of pluton crystallization. Instead, considering only the U-Pb zircon ages, the range of Paleozoic pluton ages can be generally grouped into Cambro-Ordovician and Siluro-Devonian suites, as suggested by Sinha et. al., (1989) to be characteristic of the southern Appalachians as a whole. Hence, additional high precision age determinations are critical to providing an accurate framework for the thermal and magmatic history, and therefore the tectonic history, of this portion of the orogen.

Kiokee belt

The extreme southeastern portion of the study area is underlain by the strike extension of the Kiokee belt. Secor et. al., (1986) report that immediately adjacent to the study area, in South Carolina, Kiokee belt lithologies are similar to those in the adjacent Carolina terrane. However, the two terranes are separated by the Modoc zone, a steeply dipping zone of mylonitic rocks which record ⁴⁰Ar/³⁹Ar cooling ages of 285-295 Ma and 268-290 Ma (Secor et. al., 1986) This deformation zone has been traced into Georgia by students of Dr. D. Secor (USC) and by graduate students at the University of Georgia. Although the Kiokee belt records widespread Alleghanian deformation and plutonism northeast of the study area, this has not been documented in Georgia.

In summary, the majority of the geochronological work in this portion of the southern Appalachians emphasizes cooling ages. While argon data stress this point, the significance of many previously determined Rb-Sr isochron ages are debatable; the bulk of these ages probably represents a cooling age of some sort, due to minor mineral alteration and/or deformation (Bell and Blenkinsop, 1978; Black et. al., 1978; Field and Raheim, 1979; Welin et. al., 1983; Matheny and Brookins, 1984). Since different tectonic settings record plutonism of variable duration (e.g. Pitcher, 1982), it is not clear how much time elapsed between pluton emplacement, deformation, and cooling below temperatures where isotopic systems become closed. In regions where metamorphic temperatures significantly outlasted pluton emplacement and deformation, cooling ages may severely underestimate the ages of pluton emplacement. From this aspect, tectonic models based on pluton ages, and the timing between emplacement and deformation, may be misleading.

CHAPTER III: ANALYTICAL METHODS AND RESULTS

Analytical Methods

Selected samples of granite (approximately 25-35 kg each) and mafic enclave were ground in a hardened steel shatterbox and analyzed for whole-rock major and trace element analyses, rare earth element content, mineral compositions (including ferrousferric ratios for selected biotites), and Rb-Sr isotopic compositions. Details of analytical procedures are given below.

Whole Rock Chemistry

Both the Danburg and Sandy Hill plutons are relatively compositionally and texturally homogenous. Careful selection of whole rock samples, based on the relative proportions of plagioclase and potassium feldspar, yielded nine samples each of the Danburg and Sandy Hill plutons that were chosen for chemical analysis by X-ray fluorescence. Mafic enclaves, restricted to the Danburg pluton, are significantly more diverse in composition and texture. Eighteen mafic enclaves and two mafic schlieren from the Danburg pluton were also analyzed by XRF.

Analyses of major elements were carried out on fused glass disks prepared following a modification of the method of Norrish and Hutton (1969). Disks were analyzed at Georgia State University on a Rigaku 3070 wavelength dispersive spectrometer utilizing a side- window Rh target tube operated at 50 kV and 50 mA. Data were corrected for peak overlap and mass absorption effects.

Trace element analyses were done at the University of Georgia Center for Applied Isotope Studies on a Philips 2.4 kW Magix system equipped with a Rh anode tube and a sequential spectrometer. Power settings varied according to the element of interest. Trace element data were corrected for peak overlaps and mass absorption effects. All analytical lines used were K α except for Ba, Hf, U, and Th, for which the L α line was chosen. Results of separate standard analyses analyzed as unknowns are listed in Appendix 1.

Rare Earth Element Analyses

One representative sample each from the Danburg pluton and Sandy Hill plutons, mafic schlieren, and a late-stage aplite were chosen for REE analysis by neutron activation analysis. Nine mafic enclaves were also analyzed, representing three endmember textural varieties. Aliquots of approximately 200 mg were analyzed following the method of Jacobs et al., (1977). All samples were irradiated at the University of Michigan at Ann Arbor. Individual samples contained an accurately weighed Ni-Cr wire of known composition, used to monitor neutron flux during activation. Gamma- ray spectra were collected at the Center for Applied Isotope Studies at the University of Georgia. Standards used for quantitation were NBS 688 and USGS BHVO-1. An inhouse standard (BP-37, Roden, 1981) was also analyzed as an independent quality check. Results of separate standard analyses analyzed as unknowns are listed in Appendix 1.

Mineral Compositions

Mineral compositions were determined at the University of Georgia using a JEOL 8600 microprobe fitted with four wavelength dispersive spectrometers for quantitative analysis and an energy dispersive detector used for imaging and qualitative scanning. Standards used for calibration and quality control were a combination of natural and synthetic mineral standards. Results of analysis of calibration standards, analyzed as unknowns, are listed n Appendix 1. Operating conditions were 15 kV beam at 10 mA. A beam size of 10 um was chosen for all analyses except feldspars, where a flared beam was used. Data were reduced using the Bence- Albee algorithm for all minerals except titanite, for which a Phi-Rho-Zee algorithm was chosen.

Ferrous- ferric iron ratios for selected biotite samples were determined by titration. The quality control standard used was CRPG MICA-Fe (values from Govindaraju, 1989). All titrations were corrected for blank values.

Rb-Sr Isotope Analyses

Rubidium and Strontium isotopic analyses were determined at the University of Georgia on a single collector, nine- inch radius Nier- type thermal ionization mass spectrometer. Depending on the grain size of the sample, between 5 and 12 kg of rock was pulverized until it passed a 200-mesh screen. Samples were then homogenized and repeatedly split until two fractions of approximately 50 mg remained. A mixed ⁸⁴Sr-⁸⁷Rb spike was added to one aliquot for isotope dilution analysis. The unspiked aliquot was used to measure ⁸⁷Sr/⁸⁶Sr. Powders were dissolved by adding 3-4 ml of a 4:1 mixture of HF and HClO4, respectively, heated overnight in sealed Teflon bombs, and dried. Dissolved residues were taken into solution with dilute HCl, and Rb and Sr were separated using a 2.5N HCl elutant in a quartz column packed with AG-50W-X8 resin. Aliquots were loaded on a single Ta filament in a matrix of HNO₃ and analyzed on a 9inch radius, single collector thermal ionization mass spectrometer. Isotopic compositions of unspiked samples were averaged from a minimum of 250 mass scans, and were corrected for mass fractionation by normalizing to an ⁸⁶Sr/⁸⁸Sr value of 0.1194. Eighteen runs of NBS 987 during the time of the analyses yielded an average ⁸⁷Sr/⁸⁶Sr value of 0.710185 ± 000053 (2 std. err). Rb blank levels were less than 4 ng. Results are listed in Appendix 1.

Descriptive Petrography And Texture

Granitic rocks

The Danburg pluton is texturally similar to many of the post-metamorphic granitoids in the Southern Appalachians. Its location and surrounding geological relationships are shown in Figures 2-1 and 2-2. The pluton is a nearly homogenous megacrystic body transitional in composition between quartz monzonite, adamellite, granite and granodiorite. Most earlier works call the pluton a quartz monzonite (Whitney and Stormer, 1977; Thurmond, 1979; Rogero, 1986; Bottrell, 1992). However, combined variability in modal quartz feldspar group ratios give rise to a variety of minor volumes of related rock types. Figure 3-1 shows an index to the locations of quarries sampled in this investigation.

The pluton is a coarsely crystalline, porphyritic granitoid containing euhedral alkali feldspar megacrysts up to 4 cm long, which are commonly mantled with Rapakivi overgrowths (Figure 3-2). Speer et al., (1980) suggest an approximately concentric flow alignment of feldspar megacrysts in the outer portions of the pluton, which becomes less ordered toward the pluton interior. Although quarries in the southern portion of the pluton show considerable outcrop- scale deviation from this pattern, the overall pattern examined here is in agreement with this geometry. The megacrysts are surrounded by a matrix of medium- to coarsely crystalline anhedral quartz, euhedral plagioclase, and euhedral to subhedral biotite. Accessory minerals include titanite, magnetite, ilmenite, allanite, and rare occurrences of epidote and hornblende. Hornblende seems restricted to areas proximal to mafic enclaves. Titanite is euhedral and in unaltered rocks does not occur in a reaction texture. Magnetite occurs as inclusions in biotite, feldspars and titanite, and as interstitial grains. Biotite is unaltered, with cleavage surfaces up to 0.5 cm long.

Whitney and Stormer (1977) extensively described feldspars in the Danburg pluton. Much of the following descriptions are taken from their paper, with additional observations noted where appropriate. Alkali feldspars are homogenous microcline perthites. They are dominantly large euhedral columnar crystals with well- developed {010} and {001} faces. They commonly include inclusions of calcic to intermediate oligoclase. Carlsbad contact and interpenetration twins are ubiquitous. Rapakivi rims are typically optically continuous plagioclase, and are compositionally similar to small, unzoned plagioclase crystals in the matrix, which are generally oligoclase. Whitney and Stormer (1977) interpreted these textures and compositions to represent magmatic crystallization of orthoclase, with rapakivi rims being the product of magmatic crystallization as opposed to subsolidus exsolution of albite. A small population of albitic rims is present, but these are not common and are distinguished optically by their patchy appearance in thin section.

Plagioclase crystals are dominantly euhedral and unaltered, ranging in size from 2 to 5 mm. They may rarely be as large as 2 to 3 cm. They are typically normally zoned from andesine cores to lower oligoclase rims, but occasionally show oscillatory zoning (Figure 3-3). Crystals may contain inclusions of hornblende, but more commonly enclose plagioclase crystals of composition An_{25} to An_{30} . The smaller crystals contain few inclusions, although they are sometimes host to small biotite crystals. Zoned crystals commonly have an irregular shaped core of andesine (to An_{41}), which is surrounded by

Figure 3-1. Sample location index map. The circled areas numbered 1 through 4 are approximate locations of quarries where samples were collected. All samples named numbered in the 100-199 range are from location 1; samples numbered 200-299 are from location 2, etc. All quarries are located off of Georgia Highway 44, which is accessed from U.S. Highway 78 north of Washington, GA.


Figure 3-2. Typical Danburg pluton texture. Typical appearance of the main phase of the Danburg pluton, note pink Ksp megacrysts with white rapakivi rims. The smaller chalky white crystals in the matrix are plagioclase.



Figure 3-3. Oscillatory zoning in plagioclase, Danburg pluton. Most crystals show normal zoning. Field of view is approximately 5 mm.



normally zoned oligoclase (An₃₀₋₄₁). Other crystals show irregular anorthite rich cores (based on extinction angles), but are not preserved well enough to yield reliable microprobe analyses. These cores are interpreted as xenocrysyts derived either from the source area or through a magma-mixing event. Most crystals show one period of normal zoning. Unusual plagioclase megacrysts are sometimes up to 2 or 3 cm in length, contain numerous inclusions of magnetite and biotite, and have poorly defined faces and terminations. This texture strongly resembles the "boxy cellular plagioclase" described by Hibbard (1991), who attributes this particular texture to non-equilibrium conditions arising from mixing of two magmas of differing thermal and chemical properties.

The informally named Sandy Hill granite (Rogero, 1986) is a medium to coarsely crystalline pink equigranular granite. Outcrops of this body are sparse, and are found as a thin envelope along the southernmost quarter of the Danburg pluton (see Figure 2-2). No contact metamorphic aureole has been documented where the two plutons are in contact. In one small exploration pit in the Sandy Hill granite on the southeastern side of the Danburg pluton, phenocrysts of microcline up to 2 cm long are commonplace. Mafic enclaves have not been observed anywhere in the Sandy Hill granite.

In the Sandy Hill granite, microcline is the dominant feldspar. It is microperthitic, subhedral to euhedral, and contains small inclusions of plagioclase, sometimes containing cuneiform quartz. Plagioclase is subhedral to anhedral oligoclase or andesine and averages 2-3 mm in length. Feldspars are highly altered, thus sericite and epidote group minerals are common. Biotite is usually partly to severely altered to chlorite along cleavage plane traces. Magnetite occurs as small euhedral to anhedral crystals of approximately 0.5 mm diameter, sometimes altered to hydrous Fe- oxides. Apatite was

reported by Rogero (1986) to occur as small anhedral crystals, but was not observed in this study.

Mafic Enclaves

A wide array of enclaves is encountered in the field. They share a common mineralogy, but vary widely in texture and modal abundance of the major minerals. They are all characterized by a distinctly finer grain size. They also contain acicular apatite and skeletal titanite, although these textures are more strongly pronounced in certain textural varieties. Representative modal analyses of each enclave type and a tonalitic sample of the Danburg pluton (DG2fg) are listed in Table 3-1. The enclaves are rounded to lenticular shaped inclusions ranging from a few tens of centimeters to 4-5 meters across. All have distinct boundaries with the host granitoid. Disregarding the obvious xenoliths of regionally metamorphosed wallrock in the body, the inclusions can be grouped into four categories based on texture. These are described below.

Ocelli

One of the dominant textural varieties of enclave is a distinctive spotted-appearing enclave (Figure 3-4). When these enclaves are lenticular shaped, individual ocelli appear slightly flattened. Ocelli enclaves comprise a dark matrix of fine-grained biotite and feldspar(s) which host leucocratic clots termed ocelli (terminology of Hibbard, 1991). Quartz is found either as small isolated crystals in the matrix, or as large (5-8 mm) rounded crystals. Thus, it can account for up to 20% of an individual thin section but rarely exceeds a few percent of the entire enclave. The ocelli contain one or both feldspars and are devoid of any dark minerals except for one or two crystals of titanite

Table 3-1. Modal analyses of enclaves and tonalite. Modal percentage of minerals in thin sections of representative mafic enclaves. Total point counts are from 400 to 500 per section.

	Qtz	Kfs	P1	Bt	Ttn	Hbl	Mag	Ар	Zrn /
									Aln
DG 320	7.0	2.4	22.8	44.0	8.7	tr	12.1	2.7	0.1
DG 105 E	17.3	4.6	55.1	14.6	4.0	tr	3.1	1.1	0.2
DG 205 E	20.2	24.3	36.3	12.3	3.7	tr	1.5	0.9	1.1
DG 304 E	22.5	42.9	23.7	6.8	2.6	tr	0.9	0.5	0.2
DK 305 E	20.0	0.0	46.9	24.2	4.2	1.5	1.0	2.0	0.2
DG 204 E	9.4	33.3	35.0	14.5	3.8	0.0	2.6	0.9	0.4
DG 207 E	18.1	8.1	43.5	19.5	3.0	3.2	2.1	1.9	0.7
DG 307 E	2.4	10.8	43.6	35.2	4.4	tr	2.0	1.6	0.0
DG 2FG	23.0	6.0	35.0	26.0	4.0	tr	4.0	2.0	tr

centered within the ocelli. This texture in enclaves has been described only rarely (Hibbard, 1991; Baxter and Feely, 2002).

The matrix is composed primarily of biotite and one or both feldspars, occasionally containing a few percent quartz. Biotite (20-30%) is dark green-brown to brown, anhedral, and 0.25 to 0.50 mm across. Plagioclase is commonly lath-shaped, around 0.5 mm in length, and euhedral to subhedral. It is ubiquitously twinned and at least slightly zoned. Most crystals show only one period of normal zoning but oscillatory zoning is sometimes observed. It occasionally occurs as crystals 3 to 4 mm long with an extreme aspect ratio. Potassium feldspar, like plagioclase, varies from euhedral to anhedral, but euhedral crystals are always present. Typical size ranges are similar to plagioclase. Kspar is conspicuously twinned by both albite and pericline laws, but some crystals are pericline only. Hornblende, where present, can comprise 3 to 4 % of the enclave. It occurs as euhedral to subhedral crystals up to 7 mm in length. It is sometimes replaced partly by biotite, but clean crystals are common. On rare occasions it has a slightly skeletal appearance (Figure 3-5). Titanite is typically 2-3 mm in length. It has a characteristic skeletal morphology where small crystals of feldspar are partly enclosed by the titanite (Figure 3-6). The textural term "ophitic" was adopted by Hibbard (1991) to describe this texture in enclaves, and is now widely used in enclave descriptions. Apatite is an abundant acessory mineral, and is highly acicular in habit.

Coalesced Enclaves

The informally named, "coalesced" variety of enclave is the most variable appearing of all types. Their appearance can range from a slightly hybridized type of ocelli enclave to rather felsic compositions characterized by lobate-cuspate contacts Figure 3-4. Typical appearance of an ocelli enclave. Note the slightly flattened ocelli aligned with the long axis of kspar megacrysts in the upper photograph. This is common only when the enclave has a lenticular shape.





Figure 3-5. Enclave amphibole, with possible skeletal texture. Amphibole in an ocelli enclave; the middle crystal shows the less common incipient skeletal or poikilitic appearance. Field of view is approximately 5 mm.



Figure 3-6. Skeletal titanite texture. Typical appearance of skeletal titanite in the ocell or coalesced varieties of mafic enclave. The clear areas immediately surrounding the titanite comprise small ophitic plagioclase laths of nearly unzoned plagioclase and/or potassium feldspar. Field of view is approximately 5 mm.



between internal light and dark portions (Figure 3-7). They appear to represent variously digested or hybridized ocelli enclaves. Regardless of their overall appearance, they have a color index intermediate to the host granite and the ocelli enclaves.

Plagioclase and potassium feldspar crystals span a wide size range, up to 3 cm in length. Zoning in plagioclase is dominantly normal, and some contain abundant poikilitic quartz.

Biotite is similar to that seen in the ocelli enclaves, but can reach 3 to 3.5 mm across in the more leucocratic varieties. In contrast to the ocelli enclaves, some thin sections show anhedral titanite clustered with anhedral opaque oxides; this is likely a reaction texture. With this minor exception, titanite is always at least somewhat skeletal in appearance, and apatite always shows a higher aspect ratio than in the host granite, although not always as extreme as seen in the ocelli enclaves.

Microgranitoid Enclaves

The microgranitoid enclaves, while still common in the Danburg pluton, are less abundant than previously described groups. They are lighter in color, more coarsely crystalline and more homogenous than other enclaves (Figure 3-8). Overall, they are equigranular and much less likely to contain feldspar megacrysts. Most contain both feldspars, but one can be very dominant.

Most minerals are typically 2-4 mm across. Plagioclase shows normal and occasionally oscillatory zoning; overgrowths are present on some crystals. Microcline is largely anhedral to subhedral, twinned by pericline and carlsbad laws. Quartz is always present, sometimes approaching 20% by volume. Biotite is characterized by ragged edges, a texture common to all enclaves described. Hornblende is conspicuously absent

in the microgranitoid variety. Titanite is euhedral, 0.5 to 0.75 mm long, and rarely shows the skeletal habit seen in other textural varieties of enclave. Apatite also is stubbier in habit, but remains more highly elongate than in the host granitoid.

Mafic Schlieren

Mafic schlieren are restricted in occurrence to the Danburg pluton, and are readily distinguishable from the mafic enclaves. They contain the same mineral assemblage as the granites, but modal proportions are different. They have a streaky or otherwise ill-defined shape, and are composed dominantly of biotite and plagioclase. Plagioclase is present as euhedral crystals and as intercumulus grains. Titanite is invariable euhedral. All minerals in the mafic schlieren are noticeably more coarsely crystalline than in the mafic enclaves.

Whole Rock Chemistry

Major elements

Whole rock sampling was designed to yield the widest possible spread on a Rb-Sr isochron plot. Therefore, while the bulk of the pluton is quartz monzonitic, my sampling reveals a wider array of compositions, although some of these rocks are volumetrically diminutive. Given the megacrystic character of the pluton, modal classifications are tentative at best, and normative or cationic classification schemes are preferred, although these are also somewhat ambiguous. The classification of Barker (1979), based on the molecular normative AN-AB-OR ratios, places most analyses in the granite field, with some plotting as granodiorites. The classification scheme of Streckeisen and LeMaitre (1979), also based on molecular normative parameters, indicates that most Danburg samples are monzonites, although these scatter into the granite and quartz syenite fields. Figure 3-7. Examples of variously hybridized coalesced enclaves. The top photo displays the somewhat rare lobate-cuspate contacts between mafic and felsic portions of the enclave. The lower photo shows an enclave representative of the other extreme of the coalesced enclave, where the appearance is that of a slightly hybridized ocelli- type enclave.



Figure 3-8. Typical example of the microgranitoid enclaves. This variety is the most homogenous and uniform of all types in the Danburg pluton. The acicular and skeletal morphology which charaterizes apatite and titanite in the other varieties is much less pronounced in this type of enclave.



The normative classifications reflect the solid solution in the feldspars, and should provide a more accurate estimate of overall composition (Rollinson, 1993). Cation-based classification schemes (Debon and LeFort, 1988; De la Roche et al, 1980) plot most analyses within the granite field or along the granite-adamellite border.

Both the Danburg and Sandy Hill plutons contain approximately 5% K₂O. The Sandy Hill rocks are depleted in CaO relative to the Danburg samples. With rare exception, Danburg rocks are not corundum normative, whereas Sandy Hill rocks consistently contain corundum in their norm. Molar A/CNK ratios of Danburg rocks are metaluminous and span the range 0.98 to 1.11, with an average value of 0.95. Sandy Hill samples span the range 0.98 to 1.11, with an average value of 1.04. Finally, the Danburg rocks are exceptionally pristine, whereas the Sandy Hill rocks are characterized by extensive deuteric alteration.

Eighteen whole rock granitoid analyses and 20 whole rock enclave and schlieren analyses are plotted in Figures 3-9 and 3-10 and compiled, along with normative parameters, in Appendix 2. Table 3-2 lists a few representative analyses. The Danburg granite samples have SiO₂ contents which vary continuously from 63.0 % in a finergrained, equigranular, tonalitic zone of the pluton several meters across (sample DG 2fg) to 72.5 % (sample DG 2-X). Additionally, an aplite (sample DG 310) is quite silica- rich (74.9%). A sample of mafic schlieren is the poorest in silica (57.8%). When plotted against SiO₂ in Harker- style variation diagrams, most major and trace elements show curvilinear or curved trends, although scatter at SiO₂ concentrations above 71-72 % are problematic. Fe₂O₃, P₂O₅, TiO₂, CaO, Al₂O₃, MnO and MgO correlate negatively with SiO₂. Al₂O₃ and CaO appear to show separate trends between the two plutons, but scatter at high SiO₂ concentrations makes this interpretation ambiguous. With the exception of the mafic schlieren and the finer grained equigranular samples, K_2O is generally constant with respect to SiO₂, while Na₂O is slightly inversely correlated with SiO₂. Total alkalis ($K_2O + Na_2O$), however, show a slight enrichment trend with increasing SiO₂. Sandy Hill granite samples range from 71.6 % SiO₂ (sample SH 501) to 77.3 % (sample SH 450). The major element trends in the Sandy Hill rocks are somewhat more problematic than in the Danburg samples. Sandy Hill granite major element trends generally extend beyond those described for the Danburg pluton, but are more highly scattered. Sandy Hill granite TiO₂, Fe₂O₃, MgO, P₂O₅, K₂O, and (Na₂O + K₂O) lie on a continuation of the Danburg major element arrays. CaO is depleted relative to the Danburg rocks, While Al₂O₃ is slightly elevated. Na₂O in the Sandy Hill rocks is very scattered and shows no coherent relationship with the Danburg data.

Trace elements

Trace element whole rock data are plotted as variation diagrams in Figure 3-10. Again, scatter above SiO₂ values of 71 or 72 % is problematic. Between 62 and 70 % SiO₂, the elements Ni, Cr, V, Nb, and possibly Zr define curved trends, however Cr actually appears to systematically increase above 71 or 72 % SiO₂. However, all samples were ground in a hardened steel shatterbox, so Cr contents are suspect. As with the major element data, it is generally not possible to identify separate compositional trends between the Danburg and Sandy Hill plutons. Consequently, the Sandy Hill data would appear to be compatible with plausible differentiates of the Danburg magma. Data for Rb, Sr, and Ba, however, define distinctly different and coherent variation trends.

wgt. %	DG2FG	DG302	DG303	<u>89DG1</u>	<u>SH412</u>
SiO2	62.97	64.34	70.95	71.8	72.2
TiO2	1.17	0.84	0.23	0.42	0.36
A12O3	15.88	15.51	14.47	14.29	13.5
Fe2O3	5.69	4.08	1.35	2.09	2.15
MnO	0.12	0.76	0.02	0.05	0.06
MgO	2.84	1.74	0.44	0.92	0.5
CaO	4.07	2.74	2.05	1.79	1.3
Na2O	4.34	4.21	3.83	3.3	3.62
K2O	2.54	4.02	5.59	5.25	5.04
P2O5	0.39	0.24	0.08	0.09	0.08
H2O+	0.74	0.62	0.31	0.38	0.53
totals	100.75	<u>99.1</u>	<u>99.32</u>	<u>100.38</u>	<u>99.34</u>
ppm					
V	57	49	1	27	11
Cr	52	26	21	19	17
Ni	21	18	17	13	16
Zn	191	131	133	159	136
Nb	41	10	9	17	26
Rb	134	178	155	182	659
Sr	313	295	405	380	63
Y	28	14	14	17	3
Zr	305	130	124	143	110
Ba	725	892	905	809	965
normative %					
Q	16.15	16.78	23.29	27.56	28.55
С				0.14	
OR	15.01	23.76	33.04	31.03	29.79
AB	36.73	35.63	32.41	27.92	30.63
AN	16.35	11.55	5.78	8.29	5.7
WO			0.04		
DI-DI	1.01	0.37	2.36		0.18
HY-EN	6.61	4.12		2.29	1.16
MT		0.05			
IL	0.26	1.6	0.04	0.11	0.13
HM	5.69	4.05	1.35	2.09	2.15
TN	0.91		0.51		0.16
RU	0.66			0.36	0.23
AP	0.92	0.57	0.19	0.21	0.19

Table 3-2. (Following 2 pages) Representative XRF whole rock analyses of the Danburg pluton, (DG) Sandy Hill granite (SH), and mafic enclaves (E). See Appendix A for statement of accuracy and precision.

wgt. %	SH411	SH410	DG200LE	DG105E	DG206E
SiO2	74.06	75.43	64.25	63.02	58.71
TiO2	0.11	0.11	1.07	1.13	1.78
A12O3	13.87	13.13	15.28	15.62	15.36
Fe2O3	0.84	0.87	5.13	5.95	7.26
MnO	0.05	0.03	0.08	0.12	0.13
MgO	0.17	0.14	1.4	2.74	2.22
CaO	0.61	0.59	2.96	4.09	4.01
Na2O	3.77	3.82	3.53	4.26	3.17
K2O	5.35	4.89	5.5	2.73	4.03
P2O5	0.01	0.02	0.3	0.38	0.65
H2O+	0.44	0.37	0.77	0.32	0.83
totals	<u>99.28</u>	<u>99.4</u>	<u>100.27</u>	<u>100.36</u>	<u>98.15</u>
ppm					
V	13	24	72	114	115
Cr	18	20	15	60	54
Ni	18	15	8	33	12
Zn	141	133	193	192	202
Nb	27	29	57	32	72
Rb	600	268	150	154	145
Sr	77	235	445	322	287
Y	3	17	29	22	31
Zr	108	203	415	325	402
Ba	955	869	611	616	431
normative %					
Q	30.12	33.08	15.08	16.01	14.77
С	0.79	0.53			0.05
OR	31.62	28.9	32.5	16.13	23.82
AB	31.9	32.33	29.87	36.05	26.82
AN	2.96	2.8	9.6	15.4	15.65
WO					
DI-DI			2.43	1.85	
HY-EN	0.42	0.35	2.36	5.97	5.53
MT					
IL	0.11	0.06	0.17	0.26	0.28
HM	0.84	0.87	5.13	5.95	7.26
TN			2.2	1.67	
RU	0.05	0.08	0.08	0.31	1.63
AP	0.02	0.05	0.71	0.9	1.54

Table 3-2. (continued) Representative XRF whole rock analyses of the Danburg pluton, (DG) Sandy Hill granite (SH), and mafic enclaves (E).

Figure 3-9 Silica variation diagrams for mafic enclaves: major elements. Harker variation diagrams of major element XRF analyses from the Danburg pluton, Sandy Hill granite, and mafic enclave suite. Symbols are: Danburg pluton = solid circles; Sandy Hill granite = open circles; mafic schlieren = solid triangles; ocelli enclaves = asterisks; microgranitoid enclaves = open diamonds; and coalesced enclaves = crosses. (following 4 pages)









Figure 3-10 Silica variation diagrams for mafic enclaves: trace elements. Harker variation diagrams of trace element XRF analyses from the Danburg pluton, Sandy Hill granite, and mafic enclave suite. Symbols are: Danburg pluton = solid circles; Sandy Hill granite = open circles; mafic schlieren = solid triangles; ocelli enclaves = asterisks; microgranitoid enclaves = open diamonds; and coalesced enclaves = crosses. (following 4 pages).









Mineral Chemistry

Danburg Pluton Feldspars

Figure 3-11 compares plagioclase compositions from the granitoids and the enclave suite. Analyses from the Danburg pluton are further subdivided into into cores, intermediate zones, and rims. This was not done in the enclaves because weak zoning makes many core and intermediate compositions indistinguishable.

Plagioclase compositions from the Danburg pluton span the range An_{46} to An_1 , but most are clustered in the range An_{33} to An_{20} . In this latter range there is considerable overlap between core, intermediate, and rim compositions. Overall, compositional gaps occur between An_{33} and An_{27} and also between An_{20} and An_5 .

Five of the rim compositions shown in Figure 3-11 represent rapakivi rims on K-spar phenocrysts within the enclaves. These are mostly in the $An_{20} - An_{18}$ range of composition. The most albitic rims are rapakivi rims which exhibit a patchy appearance in thin section. In contrast, optically clean rapakivi rims have a composition similar to small unzoned plagioclase crystals in the matrix. Whitney and Stormer (1977) concluded that the highly albitic, patchy rims are most likely exsolution products formed during subsolidus re-equilibration.

Mafic enclave Feldspars

Plagioclase in the mafic enclaves can be grouped into three textural categories. The first and most abundant example is a population of fine-grained, mm-scale laths of plagioclase which, along with biotite, comprise the bulk of the enclave matrix (Figure 3-12). These crystals are usually unzoned except for their outermost rims. A second textural variety is found as isolated cm- scale phenocrysts occuring within the matrix

(Figure 3-13). In hand sample these phenocrysts sometime protrude partly out of the boundary of the enclave. They can be from a few millimeters to 3 or 4 cm long. A third texturally distinct type of plagioclase is an ophitic lath found within ocelli or in coalesced enclaves. These laths are intimately associated with titanite crystals (Figure 3-14). Usually smaller than the matrix plagioclase, these crystals are also typically unzoned except for their outermost rims.

Referring to Figures 3-11 and 3-15, enclave plagioclase spans approximately the same compositional range as the host granitoid (An_{47} to An_2 .) but is more tightly clustered around An_{18-30} . One particular sieved core (not plotted) was found to have a composition of An_{85} .

The distribution of enclave plagioclase compositions shows gaps similar to that seen in the granites, although there are a limited number of analyses with compositions greater than An_{30} . The highly variable bulk composition of these enclaves (particularly their CaO/Na₂O ratios), if reflective of a melt composition, would suggest that they are likely to crystallize a wide range of plagioclase compositions, thereby explaining the spread on ternary plagioclase compositional diagrams. Alternatively, the spread could be the result of crystal accumulation.

Textural-Compositional Relationships in Mafic Enclave Plagioclase

Figure 3-15 illustrates the compositional relationships among the various textural varieties of plagioclase in the mafic enclave suite.

The larger, cm- scale phenocrysts have the widest overall compositional range, varying between An_{48-15} , excluding an outlying rim composition at measured at An_4 . In contrast, compositions of ophitic crystals are largely restricted to the range An_{28} to An_{15} ,
Figure 3-11. Ab-An-Or plots of plagioclase compositions from the Danburg and Sandy Hill plutons and the mafic enclave suite.



Figure 3-12. Enclave matrix textures. Photomicrograph of matrix crystals of plagioclase and potassium feldspar. These small, unzoned laths of plagioclase are common to all three types of mafic enclave, particularly so in the ocelli and coalesced varieties. Field of view is approximately 7 mm.



Figure 3-13. Enclave plagioclase phenocryst textures. Photomicrograph of cm- scale plagioclase phenocryst in the enclave matrix. This type of phenocryst is common to all varieties of enclave in the suite, and are more likely to be zoned than are the surrounding matrix crystals. Field of view is approximately 7 mm.



Figure 3-14. Ophitic texture of titanite and plagioclase. Photomicrograph of the ophitic relationship between plagioclase laths and skeletal titanite within an individual ocelli. These textures are preserved in the coalesced enclaves as well as the ocelli variety. They are uncommon in the microgranitoid variety of enclave. Bottom edge of photomicrograph is approximately 1.5 mm.



Figure 3-15. Textural-compositional relationships in enclave plagioclase. Summary of plagioclase compositions in the various textural varieties of the mafic enclave suite. Crosses represent the weighted mean compositions. The solid bars represent one standard deviation about the mean, and the unshaded regions encompass the total range of compositions.



with two outliers around An_8 . Since these crystals are found in leucocratic clots intimately associated with titanite in the ocelli, rapid equilibration with titanite may explain the lower and less variable anorthite contents of the ophitic crystals. Schlieren plagioclase (not plotted separately; see Appendix 3) have a restricted compositional range (largely An_{29-26}) that is similar to the most commonly measured compositions in the mafic enclave suite.

Sandy Hill Granite Feldspars

Plagioclase compositions from the Sandy Hill granite are shown in Figure 3-11. Plagioclase compositions are variable, but An contents greater than 30 are absent. As in the case of the Danburg samples, there is some overlap between core, rim, and intermediate zone compositions. Core compositions range from An_{27-13} . Rim compositions range from An_{16} to nearly pure albite, while intermediate zone compositions range from An_{26-11} . Rapakivi rims were not noted in the Sandy Hill samples.

In summary, plagioclase compositions from the Danburg pluton, associated mafic enclaves, and the Sandy Hill granite are all characterized by considerable overlap between core, intermediate, and rim zone compositions. The Danburg granitoids exhibit a tri-modal plagioclase compositional distribution with the bulk of compositions approaching the mean value. This is less pronounced in the mafic enclave suite. Within the enclaves, there are distinct but overlapping compositional ranges for the various textural varieties. Plagioclase compositions more calcic than An_{30} are absent from the Sandy Hill pluton; plagioclases in this pluton tend to cluster in two groups between An_{10} .

Biotite

Biotite is the dominant mafic phase in the Danburg pluton, forming up to 5% modal volume of the main phase of the pluton, up to 26% of the finer grained tonalitic samples, and up to 44% of the mafic schlieren. In the mafic enclaves it can range from 7% by volume in the highly coalesced enclaves up to 35% of the ocelli-type enclave.

In the granite individual biotite flakes can be up to 6 mm across, but are typically 2-3 mm. Biotite is commonly less than 1 mm across in the mafic enclaves. It is pleochroic yellow-brown to dark brown in all rock types described herein. In the granites it occurs interstitial to the leucocratic phases, and in mafic enclaves it is sometimes segregated into areas where it is the dominant phase.

Microprobe analyses are compiled in Appendix 4. Analyses were recalculated on the basis of 22 oxygen atoms and full hydroxyl site occupancy (e.g. OH + F + Cl = 4). Figure 3-16 shows that biotite compositions lie just to the Mg-rich side of the phlogopiteannite join.

Compositional zoning in Danburg biotite is minimal. A few subtle compositional differences appear to be preserved between biotite in various textural groupings, but these differences are less than the analytical and statistical errors involved. Titanium contents appear to be slightly lower in the enclave and schlieren (0.27 per formula unit) than in the granitic rocks (0.30). One probably real compositional difference is the potassium content, as reflected in the mole fraction siderophyllite component. This is lowest in the enclaves (average Xsid = 0.19) and highest in the schlieren (0.31). The siderophyllite component in the granitoid biotites (0.20 to 0.21) is only slightly higher than in the average enclave biotite.

Figure 3-16 also compares Danburg biotite compositions with other southern Appalachian post-tectonic plutons and also illustrates two further compositional distinctions in the biotites from the Danburg and associated rocks. Mafic schlieren from the Danburg pluton show the most variable Fe / (Fe + Mg) values, whereas the finer grained tonalitic samples have the most tightly clustered values. Tetrahedral aluminum is most variable in the enclaves while most tightly clustered in the tonalitic samples. As a group, the tonalitic rocks and the mafic enclaves have the most iron-rich compositions (compared to magnesium contents), whereas the mafic schlieren contain the most magnesian biotites.

Compared to other southern Appalachian post-tectonic plutons, biotite compositions within the Danburg pluton most closely resemble those in the Siloam pluton, located approximately 50 km to the southwest and also within the same lithotectonic belt as the Danburg pluton. While having approximately the same range of Al^{IV} values as the Siloam and Landis plutons, the Danburg biotites are noticeably more magnesian than those analyzed in any of the other southern Appalachian post-tectonic granitoids.

Amphibole

Amphibole microprobe analyses are compiled in Appendix 5. Representative analyses are given in Table 3-3. The Sandy Hill granite did not crystallize amphibole; in the Danburg granitoids it occurs very sparsely and is most likely to be found proximal to the mafic enclaves. It is nearly ubiquitous in the enclaves, but was not observed to exceed 4 percent modal abundance. It occurs as euhedral to subhedral prismatic crystals up to 7 mm long in the granitoid, and in smaller crystals in the enclaves. In the latter rocks it sometimes forms a mildly skeletal or poikilitic morphology, although this is not common

	DG	DG 101	205 E	205 E	209 E	209 E	207X	207X
	101							
	core	rim	core	rim	core	rim	rim	interior
SiO2	43.90	43.83	43.61	43.87	43.96	44.18	43.23	44.22
TiO2	1.35	0.92	1.38	1.04	1.41	1.15	0.99	1.52
Al2O3	8.31	8.54	8.10	7.99	8.45	8.47	8.82	8.18
Fe(t)(FeO)	18.12	18.74	17.00	16.87	18.00	18.11	17.36	17.41
MnO	0.85	0.74	0.84	0.85	0.68	0.53	0.84	0.87
MgO	10.80	10.45	10.82	10.78	10.41	10.63	10.67	11.24
CaO	11.43	11.62	11.23	11.18	11.42	11.58	11.60	11.57
Na2O	1.57	1.55	1.65	1.69	1.47	1.46	1.53	1.58
K2O	1.28	1.27	1.18	1.16	1.21	1.15	1.24	1.26
BaO	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
F	1.02	1.05	0.95	0.76	0.74	0.79	0.92	0.99
Cl	0.13	0.11	0.13	0.10	0.10	0.09	0.08	0.12
Sum(ox)	98.28	98.33	96.44	95.99	97.50	97.77	96.86	98.50
Formula								
calculation			23 O	basis				
sum cats	15.773	15.794	15.737	15.733	15.697	15.709	15.779	15.758
Si	6.599	6.576	6.644	6.686	6.613	6.614	6.535	6.619
Ti	0.153	0.104	0.158	0.119	0.160	0.129	0.113	0.171
Al	1.472	1.510	1.454	1.435	1.498	1.494	1.571	1.443
Fe3+	0.583	0.753	0.584	0.675	0.702	0.771	0.835	0.507
Fe2+	1.695	1.598	1.581	1.475	1.563	1.496	1.359	1.673
Mn	0.108	0.094	0.108	0.110	0.087	0.067	0.108	0.110
Mg	2.420	2.337	2.457	2.449	2.334	2.372	2.404	2.508
Ca	1.841	1.868	1.833	1.826	1.841	1.857	1.879	1.855
Na	0.458	0.451	0.487	0.499	0.429	0.424	0.448	0.459
Κ	0.245	0.243	0.229	0.226	0.232	0.220	0.239	0.241
Ba	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000
F	0.485	0.498	0.458	0.366	0.352	0.374	0.440	0.469
Cl	0.033	0.028	0.034	0.026	0.025	0.023	0.020	0.030
OH	1.482	1.474	1.509	1.608	1.622	1.603	1.540	1.501
ox+H2O	99.77	99.82	97.94	97.58	99.13	99.39	98.40	100.01
Fe3/Fe(t)	0.256	0.320	0.270	0.314	0.310	0.340	0.381	0.232
sum[vi+iv]	13.029	12.973	12.987	12.949	12.956	12.944	12.926	13.030
sum[vi]	5.029	4.973	4.987	4.949	4.956	4.944	4.926	5.030

Table 3-3. Representative amphibole compositions from the Danburg pluton (DG) and mafic enclaves (E). Mineral recalculation scheme of Holland and Blundy, 1994.

Figure 3-16. Comparative biotite compositions. Plot of biotite compositions from the southern Appalachians onto the phlogopite- annite- eastonite- siderophyllite field. Data from other plutons was taken from original and compiled data in Speer (1987).



(see Figure 3-5). Grains are pleochroic dark yellow green to greenish brown. They sometimes appear partly replaced by biotite, but clean crystals are common. Microprobe analyses plot in the edenite field of Leake (1998) and are plotted in Figure 3-17. Table 3-4 summarizes averages of all amphibole analyses. They have a relatively narrow compositional range with Fe/(Fe+Mg) ratios slightly lower in the schlieren (0.44) than in the enclaves or granites (0.48 and 0.49, respectively). They have uniform Si contents in the half-unit-cell formula ranging from 6.5 to 6.7 atoms per 23 anions; these are indistinguishable regardless of which rock type in which they occur. The average F and Cl contents range between 0.20 mol% F/(OH+F+Cl) in the enclaves to 0.25 mol% in the granites. Mol% Cl/(OH+F+Cl) ranges from .009 in the schlieren up to .014 in the enclaves. Microprobe analytical uncertainties associated with the halogens likely render these latter values indistinguishable, although the Fe/(Fe+Mg) differences are interpreted as realistic and within analytical uncertainty.

Average Al_2O_3 content in amphiboles is analytically indistinguishable between the schlieren, enclaves and granites. Average CaO content ranges from 11.6% in amphiboles from the granites and schlieren to 11.4% in the enclaves. Average TiO₂ content is highest in the enclave amphiboles (1.21%) and lowest in the granites (0.99%). Average MgO content is analytically indistinguishable in the enclave and granite amphiboles but is highest in the mafic schlieren (1% absolute; 9% relative), while total Fe as FeO ranges from 18% in the granite amphiboles to 16.3% in the schlieren.

In most cases zoning from core to rim is inconsistent. The exceptions are TiO_2 , which is strongly zoned in the enclave amphiboles, where rim compositions (1.0 % TiO_2) are depleted 25% relative to the cores (1.4 % TiO_2). Similar zoning is not observed in

	enclaves	1s	cores	interm.	rims
SiO2	43.82 +/-	0.40	43.96	43.94	43.68
TiO2	1.21 +/-	0.24	1.39	1.33	1.04
Al2O3	8.29 +/-	0.27	8.15	8.17	8.44
Fe(t)(FeO)	17.52 +/-	0.50	17.32	17.38	17.73
MnO	0.74 +/-	0.10	0.75	0.81	0.72
MgO	10.76 +/-	0.28	10.89	10.88	10.62
CaO	11.38 +/-	0.15	11.36	11.42	11.39
Na2O	1.57 +/-	0.08	1.59	1.59	1.56
K2O	1.20 +/-	0.04	1.21	1.20	1.19
F	0.85 +/-	0.10	0.86	0.95	0.82
Cl	0.11 +/-	0.03	0.11	0.12	0.10
BaO	0.02 +/-	0.03	0.01	0.02	0.02
	granites	1s	cores	interm.	rims
SiO2	43.82 +/-	0.44	43.77	44.00	43.81
TiO2	0.99 +/-	0.19	0.99	1.12	0.96
Al2O3	8.52 +/-	0.25	8.49	8.22	8.60
Fe (t)(FeO)	17.97 +/-	0.40	18.15	18.05	17.86
MnO	0.81 +/-	0.06	0.81	0.87	0.80
MgO	10.70 +/-	0.25	10.79	10.73	10.65
CaO	11.58 +/-	0.13	11.57	11.44	11.61
Na2O	1.52 +/-	0.11	1.53	1.59	1.50
K2O	1.22 +/-	0.04	1.22	1.24	1.22
F	1.05 +/-	0.06	1.05	1.08	1.04
Cl	0.08 +/-	0.03	0.07	0.10	0.08
BaO	0.00 +/-	0.00	0.00	0.00	0.00
-	schlieren	1s			
SiO2	44.12 +/-	0.25			
TiO2	1.07 +/-	0.274			
Al2O3	8.65 +/-	0.276			
Fe(t)(FeO)	16.34 +/-	1.446			
MnO	0.70 +/-	0.095			
MgO	11.77 +/-	0.868			
CaO	11.60 +/-	0.176			
Na2O	1.58 +/-	0.106			
K2O	1.21 +/-	0.02			
F	1.02 +/-	0.065			
Cl	0.07 +/-	0.012			
BaO	0.00 +/-	0.00			

Table 3-4. Averages of amphibole compositions from the Danburg pluton and the mafic enclave suite. Number of analyses are as follows: 19 enclave analyses; 16 granite analyses; 16schlieren analyses

amphiboles occurring in the granite. Total Fe as FeO is enriched from core to rim in the granite amphiboles, but the opposite behavior is observed in the enclaves. MgO is weakly zoned, decreasing from core to rim. Al_2O_3 zoning is more pronounced in the granite amphiboles, increasing from core to rim; this is less obvious in the enclaves.

Figure 3-18 compares the titanium and alkali content of the Danburg amphiboles to those compiled by Vyhnal et al. (1991) in other southern Appalachian granitoids. Also shown are analyses from the North American Cordillera (Whitney and Stormer, 1985), and the Sierra Nevada batholith (Dodge et. al., 1968). Alkalic provinces are represented in Figure 3-18 by data from the Grand Canyon basanitic lavas and Black Rock Summit (Best, 1970), Tahiti (McBirney and Aoki, 1969), and the Kerguelen archipelago (Giret et. al., 1980). The Danburg amphiboles are compositionally similar to all other occurrences in southern Appalachian granitoids except for the Pageland pluton in northeast South Carolina.

As a group, the Danburg amphiboles most closely resemble those in the Liberty Hill pluton in South Carolina, and the Megantic Complex in the White Mountain Magma Series, the main difference being their slightly lower alkali and titanium contents.

Titanite

Although less abundant than biotite, titanite is an important and ubiquitous mafic phase in all textural categories of the Danburg pluton and mafic enclaves. It did not crystallize in the Sandy Hill rocks. Microprobe analyses are listed in Appendix 6 and average analyses by rock type are shown in Table 3-5. Microprobe analyses were recalculated on the basis of 22 oxygen atoms. Average compositions of titanites from the various phases of the Danburg are all similar within analytical error. Electron backscattering images reveal a heavy element zoning in some grains, although on a scale too fine to reliably measure on the microprobe. Limited core-to-rim data from titanite in the mafic enclaves suggest that Fe_2O_3 and P_2O_5 decrease toward the rims, while F and Zr increase. While these differences are greater than analytical errors, this observation is based on only a few analyses.

One interesting aspect of the titanites in the Danburg rocks concerns the textures displayed in the mafic enclaves versus those in the granitoids. In the coarsely crystalline granitic rocks, titanite is euhedral with well formed, complete crystals. In the ocelli and coalesced enclaves, however, titanite displays a skeletal morphology where the overall crystal outline is discernable, but significant portions of the interior and exterior of the crystal did not form. These crystals often contain laths of ophitic plagioclase protruding from the crystal interior (see Figure 3-6). The microgranitoid variety of enclave, while often containing titanite with plagioclase inclusions, rarely shows the skeletal variety of titanite. It is interesting to note that the various morphologies of titanite do not preserve significant compositional differences. The one exception to this seems to be in their REE contents; titanites from the enclaves contain higher concentrations of most rare earth elements (Table 3-6). Clean mineral splits from the granitoid and the enclaves also preserve nearly identical ⁸⁷Sr / ⁸⁶Sr ratios (see below).

Apatite

Apatite is a common accessory mineral in all rock types and enclaves in the Danburg pluton. In the coarsely crystalline granitoids, it occurs as stubby prisms enclosed by biotite or titanite, and less commonly in the feldspars. Apatite was not widely analyzed as part of this study; averages are compiled in Table 3-7 and listed separately in Appendix 7. Microprobe analyses were recalculated on the basis of 26 oxygen atoms.

Major element compositions do not vary systematically with rock type. Overall, the apatite compositions are F-rich compared to analyses published in Deer et al. (1996). The highest F content observed in this data set was 6 weight % F, although averages are around 4- 5%.

Apatite habit varies considerably between the different facies of the Danburg pluton. In contrast to the stubby habit in the granitoid, it is acicular in the mafic enclaves. As is the case with titanite, this change in habit is less pronounced in the microgranitoid variety of enclave. Figure 3-19 illustrates the difference in morphology.

Rare Earth Elements

Fifteen samples were selected for analysis of REE by neutron activation. These include a representative sample of the Danburg pluton (89DBgr); the Sandy Hill granite (SH410); an aplite and mafic schlieren sampled within the Danburg pluton (DG310 and DG 202 SCH, respectively); nine mafic enclaves spanning the textural range previously described, and titanite splits from a representative sample of granite and from an ocellirich mafic enclave. Chondrite-normalized REE plots using the normalization constants of Nakamura (1974) are given in Figures 3-20(a) through 3-20(d).

	granites	schlieren	enclaves	
	n=16	n=5	n=26	
SiO2	29.98 ± 0.60	29.07 ± 0.52	30.04 ± 0.61	
Al2O3	1.90 ± 0.17	1.81 ± 0.18	1.92 ± 0.24	
FeO	2.18 ± 0.25	2.07 ± 0.24	2.10 ± 0.27	
MgO	0.05 ± 0.02	0.05 ± 0.01	0.05 ± 0.02	
CaO	26.71 ± 0.65	27.08 ± 0.80	27.14 ± 0.58	
Na2O	0.05 ± 0.03	0.04 ± 0.03	0.02 ± 0.02	
K2O	nd \pm •	nd ± 0.00	0.01 ± 0.02	
TiO2	33.95 ± 0.59	34.70 ± 0.38	34.28 ± 0.81	
P2O5	0.08 ± 0.02	0.07 ± 0.04	0.05 ± 0.03	
MnO	0.21 ± 0.03	0.17 ± 0.03	0.19 ± 0.05	
F	0.86 ± 0.07	0.96 ± 0.22	0.88 ± 0.22	
Cr2O5	nd ±	$nd \pm \bullet$	0.02 ± 0.03	
ZrO2	0.09 ± 0.06	0.07 ± 0.04	0.08 ± 0.05	
Nb2O5	0.24 ± 0.08	$nd \pm \bullet$	0.23 ± 0.08	
BaO	$0.19 \pm \bullet.07$	0.20 ± 0.02	0.17 ± 0.02	
Ta2O5	0.06 ± 0.07	$nd \pm \bullet$	0.07 ± 0.10	
Totals	96.27 ± 0.87	96.30 ± 1.92	97.00 ± 0.96	
Si	4.084 ± 0.076	3.973 ± 0.013	4.064 ± 0.068	
Al	0.306 ± 0.027	0.292 ± 0.025	0.307 ± 0.036	
Fe2	0.248 ± 0.028	0.237 ± 0.027	0.238 ± 0.031	
Mg	0.010 ± 0.005	0.010 ± 0.003	0.010 ± 0.003	
Ca	3.900 ± 0.077	3.964 ± 0.049	3.932 ± 0.059	
Na	0.014 ± 0.007	0.011 ± 0.009	0.007 ± 0.006	
K	$nd \pm \bullet$	0.000 ± 0.001	0.002 ± 0.004	
Ti	3.477 ± 0.052	3.566 ± 0.048	3.488 ± 0.081	
Р	$0.009 \pm \bullet$	0.008 ± 0.005	0.006 ± 0.004	
Mn	0.023 ± 0.004	0.019 ± 0.004	0.022 ± 0.005	
F	0.371 ± 0.031	0.414 ± 0.086	0.376 ± 0.092	
Zr	0.007 ± 0.004	0.005 ± 0.003	0.005 ± 0.004	
Ba	$0.010 \pm \bullet$	0.011 ± 0.001	0.009 ± 0.001	
Nb	0.015 ± 0.005	$nd \pm \bullet$	0.014 ± 0.006	
mg #	3.823 ± 1.401	3.953 ± 1.066	3.835 ± 1.238	
Total Cat	12.449 ± 0.044	12.502 ± 0.093	12.462 ± 0.080	

Table 3-5. Averages of titanite compositions from the Danburg pluton and the mafic enclave suite.

Table 3-6. Rare earth element concentrations of titanites from an ocelli- rich mafic enclave (DG309E) and the coarsely crystalline Danburg pluton (DG2). Determinations were made by INAA.

Rare Earth element concentrations (ppm) in titanites				
	DG2	DG304E		
Sc	67	53		
La	2547	3266		
Ce	7525	3609		
Sm	682	811		
Eu	69	78		
Yb	259	288		
Lu	19	23		
Hf	356	114		
Та	108	111.5		
Tb	68	67		

no. of analyses	n=2 n=4		n=2	n=2	
	DG 202 -	DG 202 c	D1 c	DG 101E	
SiO2	0.65	0.50	0.43	0.65	
A12O3	0.00	0.01	0.02	0.03	
FeO	0.16	0.13	0.15	0.06	
MgO	0.00	0.00	0.00	0.00	
CaO	56.18	55.19	55.79	56.88	
Na2O	0.09	0.15	0.13	0.15	
K2O	0.02	0.01	0.01	0.00	
P2O5	38.22	39.79	37.73	38.29	
MnO	0.15	0.13	0.13	0.04	
F	4.93	4.47	4.88	4.50	
Cl	0.01	0.01	0.00	0.00	
SrO	0.03	0.06	0.03	0.04	
Totals	100.42	100.43	99.28	100.63	
O=F, Cl	2.08	1.88	2.05	1.89	
Si	0.11	0.09	0.08	0.11	
Al	0.00	0.00	0.00	0.01	
Fe2	0.02	0.02	0.02	0.01	
Ca	10.40	10.13	10.46	10.52	
Na	0.03	0.05	0.04	0.05	
Κ	0.00	0.00	0.00	0.00	
Р	5.59	5.77	5.59	5.59	
Mn	0.02	0.02	0.02	0.01	
F	2.69	2.42	2.70	2.45	
Cl	0.00	0.00	0.00	0.00	
Sr	0.00	0.01	0.00	0.00	
Total Cat	13.28	12.73	13.32	13.15	

Table 3-7. Averages of apatite compositions in the coarsely crystalline granitoid (DG202 and D1) and in a typical ocelli- rich mafic enclave (DG101E)

"c" denotes analysis of surface perpendicular to the c-axis

26

26

26

26

Ox Equiv

Figure 3-17. Leake et. al. (1998) classification of amphiboles.



Figure 3-18. Comparison of amphibole compositions. Comparison of the Danburg pluton and mafic enclaves (solid diamonds), and other southern Appalachian granitoids, to data from several sources, including (1) the Sierra Nevada batholith (Dodge et. al., 1968); (2) the Fish Canyon tuff in the North American (Colorado) Cordillera (Whitney and Stormer, 1985); (3) the post-tectonic Liberty Hill pluton, South Carolina (Speer, 1987); the Carpenter Ridge tuff (Dorais, 1987); (5, 6) the Grand Canyon basanitic lavas and Black Rock Summit (Best, 1970); (7) Tahiti (McBirney and Aoki, 1969); (8) the Kerguelen archipelago (Giret et. al., 1980), and (9) Bedard (1990). Original figure taken from Dorais (1987).



Figure 3-19. Comparison af apatite habits. Photomicrographs illustrating contrasting habits of apatite in the coarsely crystalline Danburg pluton (top photo) and the ocelli- rich and coalesced variety of mafic enclave (bottom photo). The field of view in both photomicrographs is approximately 5 mm.



REE patterns of whole rocks are moderately fractionated with respect to chondrites, with (La / Lu_N) values ranging from 19 in the aplite sample to 36 in the enclaves. Titanite is noticeably less fractionated with (La / Lu_N) values about 7. Within the whole rocks, plotting (La / Lu_N) against Ce_N or Yb_N shows no systematic relationship between degree of fractionation and REE abundance. Absolute abundances of REE are greatest in the titanite separates. Whole rock abundances are greatest in the mafic schlieren, followed by the coarsely crystalline granitoids and the aplite, in decreasing abundance.

The most notable feature of the REE plots is the degree of parallelism of all the samples, and the ubiquitous presence of a negative Eu anomaly of slightly variable size (Figure 3-20a). Whole rock patterns mimic those of titanite splits, and indicate that the REE pattern of the granites and enclaves are controlled by titanite. Supporting this argument is the fact that with the exception of the Sandy Hill granite, REE concentrations increase with modal abundance of titanite. However, the range of mafic enclave compositions overlaps the granite field in the region of Yb, although it is still of higher concentration than the Danburg pluton sample itself.

Considering only the granitic rocks (Figure 3-20b), the aplite sample is the least REEenriched, although its pattern crosses that of the Danburg pluton in the region between Tb and Yb. The Sandy Hill granite is slightly REE- enriched relative to the Danburg and aplite samples, and has a slightly larger negative Eu anomaly.

The mafic enclave patterns, while still nearly parallel, show considerable variation in abundance within individual textural groupings (Figure 3-20d). Average concentrations of each textural group show the ocelli enclaves to be the most highly enriched and the coalesced the least so. The Eu anomaly is smallest in the ocelli enclaves.

Figure 3-20(a) through 3-20(d), following 2 pages. Chondrite-normalized REE plots. Comparison of REE plots for the Danburg pluton, mafic schlieren, titanite separates, Sandy Hill granite, and the suite of mafic enclaves. Symbols are as follows: filled blue X = enclave titanite; open blue X = granite titanite; filled green triangle = mafic schlieren; small open circles = upper and lower limits of all enclaves; large open red circle = Sandy Hill granite; large filled red circle = Danburg pluton; black astersisk = Danburg pluton aplite; blue crosses = average of all coalesced enclaves; red open diamonds = averages of all microgranitoid enclaves.





CHAPTER IV: GENERATION OF MAFIC ENCLAVES IN THE DANBURG PLUTON

Introduction

Mafic enclaves are common in igneous rocks, especially those associated with calkalkaline suites (Didier, 1973). They are generally believed to be products of incomplete mixing between magmas of differing composition, although several other processes can be responsible for their occurrence. The study of mafic enclaves in granites has become an important part of understanding granite petrogenesis. Since granites can represent a final product in a complex evolution of silicate melt systems, they may preserve little of their early history. Mafic enclaves may therefore serve as a window into the earlier history of the parental magma. Since there remains some ambiguity concerning the environment in which the Alleghanian granitoids of the southern Appalachians formed (Samson et al., 1995; Speer and Hoff, 1997), the mafic enclaves in these rocks are of heightened importance. Yet they remain poorly understood, and, indeed, hardly studied at all. The one exception is the enclave suite in the Appling granite, briefly described by Nusbaum et. al.(1992). Here, I attempt to discern the origin of the mafic enclaves in the Danburg granite, in order to illuminate the early history of the pluton. This, in turn, will hopefully aid in the interpretation of the specific tectonic environment in which the Danburg pluton formed.

Review of the Main hypothesis of Enclave Formation

Mafic enclaves can be broadly grouped into two major categories: those that originated as a solid and those whose origin was as a liquid. Enclaves arising from solids may be either xenoliths or restite material. Restite is often characterized by alumina-rich minerals and metamorphic textures, and is common in S-type granites (Chappell and White, 1974; White et al., 1977; Chappell, 1978). The presence of restite type enclaves
indicates that crustal anatexis was important in the formation of the host granitoid. These enclaves do not have liquid compositions, and mineral compositions should reflect those most likely to be in equilibrium with the magma during the earliest stages of its evolution (Chappell, 1984).

Enclaves that originated as liquids are characterized by igneous textures and may result from crystal segregation or, alternatively, magma mixing. If crystal segregation was responsible for an enclave population, cumulus features should dominate textures. Moreover, these enclaves would not have compositions typical of magmatic liquids. The presence of such enclaves could indicate that crystal fractionation was an important mechanism in the evolution of the granitic host. Mafic enclaves formed by mixing mafic and felsic magmas should display quench textures, which would form as the hotter, silica-poor magma rapidly cooled in the granitic magma. These presence of these enclaves could indicate that basaltic magmatism played a role in the generation of a particular granitic magma, either by providing heat for the initiation of crustal anatexis, fractionating to form siliceous magmas, hybridizing with siliceous melts, or some combination of these processes.

Origins of the Danburg Mafic Enclaves: Evidence for a Liquid Origin

Evidence for a liquid origin in the Danburg enclaves is strongest in the ocelli- and coalesced type of enclaves. These are both dominated by quench textures, such as acicular apatite and skeletal titanite. Wyllie et al. (1962) and Vernon (1983) conclude that acicular apatite can only form by quenching, and this texture in the Danburg enclaves is interpreted here as strong evidence that the mafic enclaves originated as liquids. Numerous authors have illustrated the occurrence of acicular apatite, skeletal titanite, and

skeletal hornblende in both quenched volcanic rocks and their plutonic analogs (Pabst, 1928; Didier, 1964, 1973; Reid et al., 1983; Frost and Mahood, 1987; Vernon, 1983, 1984, 1990, 1991; Dorais et al., 1990; Dorais et al., 1991). Although experimental quenching studies have only conclusively demonstrated the formation of acicular apatite, skeletal structures in early forming minerals appear common throughout quenched rocks. I also interpret the skeletal titanite in these enclaves to be indicative of quenching. Also in support of a liquid origin are fine grained chill zones along the margins of enclaves, flattened ocelli in which the crystals do not show internal strain, and cuspate-lobate contacts between biotite-rich zones and more leucocratic zones. Additionally, igneous features are commonplace in all enclaves in the Danburg pluton. For example, the euhedral and zoned nature of the plagioclase is indicative of an igneous origin (Vernon, 1983). If the enclaves represented restite of an igneous source, the plagioclase should show reverse zoning (McLellan, 1983). Other textural features of the Danburg enclaves suggestive of a liquid origin include potassium feldspars that straddle the contact between enclave and host granite; Vernon (1983) concluded that such crystals could only form during liquid-liquid interaction. Biotite commonly forms as blade biotite, also known as hydrogenic biotite, which is an unusual descriptive morphology prone to grow in areas characterized by a juxtaposition of melt and crystalline phases, such as is common in zones of mixing (Hibbard, 1991). This morphology develops when early-formed crystals physically restrict biotite growth, resulting in blade shaped crystals characterized by elongated basal sections.

The microgranitic variety of enclave described earlier is somewhat more problematic. Titanite is only mildly skeletal in this enclave variety. Acicular apatite is common, although it tends to be wholly contained within other mineral species. Overall crystal size is slightly larger than observed in ocelli and coalesced enclaves, and chilled margins are not evident. The criterion of chilled margins is difficult to evaluate here, as they are only common on larger enclaves, and no microgranitic enclaves larger than about 10-cm diameter were observed. The smaller crystal size in these enclaves, relative to the Danburg pluton, their titanite-rich mineralogy, and the apatite morphology in these enclaves suggest that they also represent products of hybridization, although they may not be as highly quenched as other enclaves.

If the enclaves originated as liquids, they should have magmatic compositions in major and trace elements. This important aspect is discussed in subsequent sections. Evaluating Whole rock Geochemical Evidence of Mixing

The evidence described above demonstrates that the enclaves originated as quenched globules of a hotter, more mafic magma. Therefore, the enclaves are interpreted as evidence of magma mixing within the Danburg pluton. The presence of mafic schlieren and a preferred orientation of potassium feldspar megacrysts in the Danburg pluton are indicative of a somewhat advanced degree of mechanical mixing. (Metcalf et al., 1995; Frost and Mahood, 1987; Larsen and Smith, 1991; John and Blundy, 1993). Consequently, the pluton must have remained above its solidus temperature for a considerable time period after magma mixing occurred.

Collectively, the enclaves and their enclosing host rocks define a nearly continuous calc-alkaline trend between SiO_2 contents of 50 and 75 weight % (Figure 4-1). There is

Figure 4-1. AFM plot of danburg and sandy hill rocks. AFM diagram showing the overall calk- alkaline compositional trend of the Danburg and Sandy Hill plutons and mafic enclaves. Symbols are as in Figure 4-1. Solid triangles are from mafic schlieren and are cunulates.



compositional overlap between the Danburg rocks and the microgranitoid and coalesced enclaves. Inclusion of the Sandy Hill granite samples extends the SiO_2 range to 77%. Most major and trace elements exhibit varying degrees of covariance with SiO_2 and on this basis could be considered a cogenetic suite.

Magma mixing or restite unmixing typically produces linear arrays on variation diagrams (Bussell, 1988; Tindle. 1991; White and Chappell, 1977), whereas fractional crystallization can produce curved or kinked arrays. However, under certain conditions, fractional crystallization can also produce linear trends for some or all elements (Wall et al., 1987). Dorais et al. (1990) argued that if fractional crystallization alone produced linear compositional variations, then mineral compositions from the resulting suite of enclaves should exhibit a continuum of concentrations consistent with crystallization from an evolving magma. This continuum is not observed in the Danburg enclaves (e.g. plagioclase compositions in Figures 3-10 and 3-11). Compositions of the Danburg rocks show too much scatter in the region of 58% to 61% SiO₂ to be considered linear. This compositional range includes the bulk of the ocelli- type enclaves. On the other hand, the compositional trends defined by the microgranitoid and coalesced enclaves, and the more SiO_{2} - poor portions of the Danburg pluton (below 68% SiO_{2}) are much more linear (e.g. see Al_2O_3 and Na_2O panels in Figure 3-10). Much of the data from the coarsely crystalline portion of the Danburg pluton is decidedly non-linear.

Examination of the silica variation diagrams suggest that for the alkalis, Fe_2O_3 , Al_2O_3 , TiO_2 , P_2O_5 , and CaO, two distinct SiO_2 -poor trends merge in the area of 60% SiO_2 (Figure 4-2). These trends are defined by samples from all three textural varieties of enclaves. Similar distinct trends were reported for enclaves in Sierra Nevada batholith

rocks by Dorais et al. (1990), and these authors were able to attribute the second trend to a second and distinct magma comprising tholeiitic dikes and tonalitic hybrid rocks. In the Danburg enclaves, the divergent trends are defined by enclaves that are indistinguishable on textural and mineralogical grounds from the remaining enclave population. Thus, it is unlikely that a second distinct magma was involved in their genesis. The divergent trends are more likely due to the preferential segregation of potassium or plagioclase feldspars, as well as titanite and apatite. Local variations in suspended crystals caused by inhomogeneous mixing and/ or fractionation effects are not rare in enclave populations (Frost and Mahood, 1987). Therefore, the divergent trends are interpreted to reflect local variations in mineralogy and composition of the hybrid zone where magma mixing occurred. Scatter is therefore induced as diffusion proceeds in either direction between enclave and host, depending on which part of the system has a higher concentration of alkali or alkaline earth elements when mingling takes place.

Another criterion for evaluating magma mixing is the variation of elemental ratios. This approach was first applied to isotope ratios by Vollmer (1976), and later expanded to include elemental concentration ratio- ratio plots by Langmuir et al. (1978). When two elemental ratios sharing a common denominator are plotted from, magma mixing should result in a linear array of data. Evaluation of the Danburg pluton and its enclaves in this manner yields mixed results.

Plotting ratios of major and trace elements sensitive to feldspar and biotite compositions, such as Al_2O_3/Ba vs. Fe_2O_3/Ba , Na_2O/CaO vs. Al_2O_3/CaO , Rb/Ba vs. Sr/Ba, and K_2O/Ba vs. CaO/Ba (Figure 4-3) produce linear arrays indicative of magma mixing. The fit of the data in Figure 4-3 suggests that the enclaves evolved in a well-

Figure 4-2. Divergent major element trends in variation diagrams. Silica variation diagrams of elements which display divergent trends at low SiO₂ values. (following 3 pages). Symbols are as in Figure 4-2.











Figure 4-3. (Following 2 pages) Mixing diagrams I. Mixing diagrams involving plots of elemental ratios sensitive to the feldspar group minerals in the enclaves and host rocks. Symbols are as in Figure 4-1.







Figure 4-4. (Following 2 pages) Mixing diagrams II. Mixing diagrams involving plots of elemental ratios sensitive to the accessory minerals present in the enclaves and host rocks. Symbols are as in Figure 4-1





mixed system dominated by precipitation of feldspars and biotite. Ratio- ratio plots of the Danburg data using incompatible trace elements are only partly successful in identifying a mixing process. Elemental ratios controlled by the accessory phases apatite, zircon, titanite and magnetite are plotted in Figure 4-4. These plots show either incoherent scatter, or some combination of linear or curvilinear trends which show varying degrees of scatter. Scatter may be indicative of metasomatic processes (Tindle, 1991) or a variable degree of removal of trace element- rich accessory phases (Tindle, 1991; Orsini et al., 1991; Langmuir et. al., 1978).

Overall, the data are compatible with a process where magma mixing and/or mingling produces a continuum of compositions controlled mainly by feldspar and biotite crystallization, but which become modified by accumulation and/or removal of accessory phases. Two distinct mechanisms are likely competing during this process; a physical separation by density, accompanied by chemical diffusion aided by residual granitic melts and exsolved volatiles (Bedard, 1990). The relative coherence of elemental behavior observed in Figure 4-3 is perhaps due to the more efficient diffusion of alkali elements compared to non-alkali elements, as has been documented by several workers (e.g. Wiebe, 1974; Reid et al., 1983: Reid and Hamilton, 1987; Christiansen and Venchiarutti, 1990: Eberz and Nicholls, 1990).

Although the exact nature of the chemical evolution of the enclaves and host rocks is subject to debate, the textural criteria for magma mixing is clear. The quench textures provide very strong evidence toward this point, and the fine grained character of the enclaves makes their origin as cumulates of fractionated minerals extremely unlikely. Similarly, an origin by remobilization of earlier formed crystals seems unlikely.

Nature of the Original Enclave Magma Composition

Many studies of magma mixing attempt to determine the original composition of the mafic liquid from which enclaves formed (e.g. Dorais et al., 1990: Dorais et al., 1991; Frost and Mahood, 1987; Didier, 1991). It is generally recognized that this is much less straightforward in plutonic rocks than in volcanic rocks, due to the prolonged time available for chemical exchange between the two magmas. Nonetheless, in the following section an attempt is made to place constraints on the chemistry of the magma responsible for the Danburg enclaves.

The lowest value of SiO₂ seen in the enclaves is approximately 57%. Therefore, if the enclaves are at all indicative of the original chemistry of the mafic magma, basalt is not a likely candidate. Although exchange processes are likely to increase the SiO₂ content of the enclaves (Wiebe, 1996), even the most mafic enclaves in the Danburg rocks contain SiO₂ contents significantly higher than would be expected in basalts. Other studies have shown that at least a portion of an enclave suite preserves some low SiO₂ compositions similar to the proposed parental enclave magma (Reid et al., 1983; Frost and Mahood, 1987; Dorais et al., 1990). Yet, the Danburg enclaves are distinctly lacking any rocks containing SiO₂ contents approximating those found in basalts. Other magmas with SiO₂ contents which approximate that of the enclaves include andesitic magmas, which are rare in the geologic context of the area, and syenitic rocks, which although rare, are indeed present in the area of the Danburg pluton.

Isotopic data can used to discriminate between various magma types that may form mafic enclaves. In the Danburg pluton, enclaves and granitic rocks plot on the same isochron, and thus yield identical initial ratios. Titanite separates from one of the most mafic ocelli type enclaves are indistinguishable from separates taken from the Danburg granite. Thus, if there was a difference in initial ⁸⁷Sr/⁸⁶Sr ratios between the liquids, it has been erased due to isotopic exchange during mingling. This leaves only the comparative study of major and minor elements as a basis for estimating the initial composition of the mafic magma.

Bulk Rock Composition of Enclaves

In Figure 4-5 enclave compositions are plotted on the total alkalis vs. silica diagrams following Irvine and Baragar (1971) and Cox et al (1979). Rock names used in the latter diagram are those of Wilson (1989), who modified the diagram for plutonic rocks. In terms of alkali versus silica contents, the rocks plot as either alkaline or subalkaline. Using common plutonic rock names, they are mostly syeno-diorites, although some samples plot near the syenite- alkali granite or syeno-diorite – quartz diorite boundaries. Using the Shand's Index (Maniar and Picoli, 1989), which plots molar Al/(Ca+Na+K) versus Al/(Na+K), the enclaves plot mostly as weakly metaluminous compositions, although some samples are weakly peralkaline or peraluminous (Figure 4-6). There is no consistent relationship between enclave textural variety and their position on these diagrams.

Chemical Exchange During Enclave/ Host Mingling

Several authors have empirically documented chemical exchange between enclave magmas and their granitic hosts (e.g. Wiebe, 1996; Weir, 1996; Reid et al., 1983; Reid and Hamilton, 1987; Christiansen and Venchiarutti, 1990; Eberz and Nicholls, 1990; Orsini et al., 1991; Seaman and Ramsey, 1992). There is also a limited amount of experimental work documenting chemical exchange between mafic and felsic liquids Figure 4-5. TAS plots of Danburg and Sandy Hill rocks. Top diagram follows Irvine and Baragar (1971);bottom plot is from Cox et al., (1979) modified by Wilson (1989) for plutonic rocks.



Figure 4-6. Aluminum saturation plot of Danburg and Sandy Hill rocks. Shands Index (Maniar and Picoli, 1989) classification of whole rock compositions. Enclaves from the Sierra Nevada rocks plot near the top of the metaluminous field.



(e.g. Watson, 1982; McCarthy and Patino-Douce, 1997). Several generalities can be made with regards to their conclusions, which are summarized below.

Alkali and Alkaline Earth Elements

Alkali diffusion is relatively fast, compared to non-alkali elements (Watson, 1982; Johnston and Wyllie, 1988; Wyllie et al, 1989). In the plutonic environment, this allows a great deal of exchange to occur, as the time at elevated temperatures is significant. Additionally, the presence of H_2O , generated as the mafic enclave crystallizes, lowers the viscosity of the remaining melt and thereby aids in diffusion. Experimentally, diffusion of alkalis has been shown to proceed until an approximate equilibrium is reached, whereby K_2O in enclaves reaches a value approximately 1.5 times its initial concentration in the mafic liquid. Sodium and the alkaline earth elements can reach up to 3 times their initial concentration (Watson, 1982). This has been inferred in natural enclaves by Wiebe (1996) and Orsini et al. (1991), who also noted that in the absence of alkali feldspar in the enclave, alkalis will combine with iron to form biotite. The alkaline earths tend to diffuse in the same direction as the alkali metals (Orsini et al., 1991). Similar behavior was noted in layered intrusions by Wiebe (1996), who also documented Ba and Mn diffusing into enclaves from the granite host. Conversely, McCarthy and Patino-Douce (1997) experimentally documented Na₂O and CaO diffusing away from a high alumina olivine tholeiite (HAOT) into an adjacent silicic liquid. Wiebe (1996) documented similar behavior of CaO, but his findings with Na₂O agreed with those of Watson (1982). Apparently, differences in behavior may be attributable to several factors, including starting compositions of end members, pressure, and temperature.

Watson's experiments were carried out using synthetic granite and basalt at atmospheric pressure and 1200 to 1400 °C, whereas those of McCarthy and Patino-Douce used HAOT and metapelite at 1290 °C and 11 kbar, in order to simulate basalt intrusion into the deep crust. The observations of Wiebe (1996) and Orsini et al. (1991) were made on natural enclaves in mid-crustal level granitic intrusions.

High Field Strength Elements

Orsini et al. (1991) and Watson (1982) concluded that the HFSE Zr and Nb diffuse from the host granite towards the enclaves. They also concluded that Y and the REE diffuse in the same direction. Wiebe (1996) confirmed this behavior, and also showed that U and Th behaved similarly. Interestingly, TiO₂ has not been extensively discussed. However, Wiebe (1996) found that it is mildly depleted in the enclaves. McCarthy and Patino-Douce (1997) concluded just the opposite, by measuring TiO₂ contents in glasses formed in their HAOT and metapelite layers, and at the interface between the two. It is at least arguable that the observations from natural enclaves reflect most accurately the behavior of TiO₂ in the Danburg rocks, given the closer similarity of end-member compositions, and the consistent behavior of other HFSE with similar charge: size ratios as Titanium.

Other Elements

Watsons' 1982 experiments found that FeO and Al_2O_3 do not migrate significantly in either direction. Wiebe (1996) confirmed this behavior in natural enclaves. All the studies cited above agree that SiO_2 will diffuse to the mafic material, and although the degree to which its concentration changes is variable, it appears to change relatively little. This has also been observed in enclaves of the Sierra Nevada Batholith (Dorais et al., 1990; Frost and Mahood, 1987), where postulated basaltic magmas of approximately 48% SiO_2 produced enclave suites where the most mafic SiO_2 contents were only 2 to 3 percent higher than the enclave parent magma. Other, more SiO_2 -enriched enclaves may well be produced by concentration of residual melt as the system crystallizes.

Finally, the experiments of McCarthy and Patino-Douce (1997) also documented the transfer of H_2O from their metapelite into the adjacent basalt. The addition of water to the basaltic compositions is also facilitated by the increase in water due to the crystallization of anhydrous minerals such as feldspar.

In summary, experimental and empirical studies of elemental exchange in enclave/granite pairs are mostly in agreement, as far as the direction of exchange. The degree to which exchange takes place appears to be highly variable. Alkalis and, to a lesser extent, alkaline earth elements exchange relatively rapidly, and tend to become enriched in the basaltic liquid. The HFSE, H₂O, and REE can be expected to diffuse into the enclaves also, while FeO, Al₂O₃, and perhaps TiO₂ are relatively unaffected. Variations in chemical gradient between the two end members are related to their compositional contrasts and the availability of H₂O. This variable rate of diffusion makes it difficult to extrapolate from enclave compositions to an original mafic end member composition.

Considerations On the Parent Mafic Liquid Composition

Major elements

In spite of the difficulties outlined above, certain constraints may be placed on the composition of the mafic liquid parental to the Danburg enclaves.

In studies of mafic enclaves in the Sierra Nevada batholith, Dorais et al. (1990) extrapolated from linear portions of silica variation diagrams to a SiO₂ content of 48%. They chose 48% SiO₂ because it was typical of high alumina basalts, and because this SiO₂ value was not radically different from their more mafic enclaves. Such an approach is not feasible in the Danburg enclaves, however, for two reasons. As previously noted, Danburg enclaves have SiO₂ values no less than 56.7%. Given the limited migration of SiO₂ predicted by Wiebe (1996), it is not feasible to expect such a large change in SiO₂ contents. On the basis of the degree to which the Danburg enclaves are quenched, and on their SiO₂ contents, the Danburg enclave suite appears to have evolved from the ocellitype enclaves. Second, for a great many elements of importance (e.g. alkalis, Ca and Mg), the degree of scatter in the low SiO₂ portion of silica variation diagrams is simply too great to extrapolate through their compositions with any degree of confidence.

As an alternative method, here I use relative diffusion efficiencies of Wiebe (1996), who analyzed enclaves, host rocks, and undisturbed basaltic layers in the gabbro-diorite unit of the Cadillac Mountain granite. These layers record the composition of basaltic magma that was injected into the Cadillac Mountain granite, and was the parent magma that generated enclaves. By normalizing enclave compositions to the average composition of the basaltic unit, he was able to derive a factor describing the relative movement of various elements between enclaves and their host granite.

Since there is so much scatter in the low SiO_2 regions of several variation diagrams of the Danburg enclaves, I use as my most mafic sample an average of all ocelli enclaves. The elemental compositions of this average enclave are then adjusted by the average degree of enrichment or depletion Wiebe observed in the Cadillac Mountain pluton. This process gives an initial magma composition with a total of nearly 130%, so clearly the degree of enrichment of some elements is overestimated. If this type of calculation is applied using the conservative estimates of enrichment, and applied only to those elements which migrate the least, the result is an estimated initial magma composition as follows: $SiO_2 = 52\%$; FeO (total) = 11.7%; $Al_2O_3 = 17.9\%$; $TiO_2 = 2.0\%$; and CaO = 8.7%. Such a composition is broadly compatible with high alumina basalts, but there remains the problem of trace element concentration observed in the enclaves.

Trace element considerations

Certain aspects of the trace element data from the enclaves are problematic, if a basaltic parent magma is to be considered as parental to the enclaves. For instance, Ba concentrations, which generally follow K₂O contents, can reach levels in excess of 2300 ppm. Elevated Ba levels are more typical of alkaline rocks (Sorenson, 1974: Larsen, 1941). To the best of my knowledge, similar Ba contents in mafic enclaves have only been reported in trachytic inclusions from the Carpenter Ridge Tuff (Dorais et al., 1991), where they range from 2000 to 7000 ppm. These inclusions were interpreted to have formed from a silica undersaturated, trachytic parent magma. Although Ba enrichment can also occur during metasomatic or hydrothermal alteration (Sheldon et al., 1987; Emmermann, 1968), the Danburg enclaves show no evidence of such alteration, e.g. sericitized feldspars or chloritized biotite.

Zirconium contents in the Danburg enclaves range from 250 to 690 ppm, and are also not compatible with a basaltic origin. In the host rocks of the Danburg pluton, Zr contents range from 97 to 308 ppm, with one exception at 515 ppm. Watson (1979) and Watson et. al. (1983) derived a zirconium saturation model predicated on the cation ratios of Na, K and Ca relative to Al and Si, and Danburg pluton Zr contents are in agreement with his predictions. However, basaltic melts are incapable of dissolving the amount of Zr recorded in the Danburg enclaves, although, as discussed previously, Zr can migrate from the silicic host to the enclave during mingling of magmas. Published data on mafic enclaves that contain Zr levels approaching those in the Danburg enclaves are rare. The only similar data found were in mafic enclaves from the Megantic Complex granites (Bedard, 1990). These enclaves hosted by granites associated with gabbro and syenite have been shown to contain up to several hundred ppm Zirconium.

In summary, Zr and Ba contents do not favor a basaltic parent to the Danburg enclaves. These data, coupled with mineral chemistry discussed in the following section, are more agreeable with a parent that evolved along a gabbro-syenite differentiation trend.

Mineralogical evidence concerning the parent mafic magma

Microprobe analyses of mineral phases within the granite and the enclaves show that mineral compositions are very similar. Either the two liquids were consanguineous, or diffusion during and subsequent to mingling has erased compositional distinctions between minerals in enclaves and granitoids. This is supported by indistinguishable ⁸⁷Sr/⁸⁶Sr initial ratios in titanite separates from enclaves and host rocks, in addition to enclaves plotting on the same isochron as granitoids. All major and minor minerals have compositional fields that overlap, and are thus unable to illustrate differences in magma compositions.

Plagioclase in the enclaves is decidedly less calcic than in enclaves elsewhere. For instance, the early-crystallized ophitic plagioclase in ocelli has a mean composition

around An_{24} (Figure 3-15). The most calcic plagioclase population is the phenocrysts in enclaves, which have a mean composition around An_{27} . In contrast, enclaves in the Dinkey Creek enclaves of the Sierra Nevada (Dorais et al., 1990) commonly reach compositions of An₇₀ or higher. These compositions are commonplace in basaltic rocks. With the exception of a few corroded cores, even the most calcic plagioclase commonly occurring in the Danburg enclaves is less than An_{50} . Therefore, it is difficult to envision these crystallizing from a basaltic parent. Plagioclase in the Danburg enclaves is more similar in composition to plagioclase from a hornblende-pyroxene gabbro in the Dutchman's Creek intrusion in South Carolina (McSween and Nystrom, 1979), where compositions range from An₅₁₋₆₃. In the Concord gabbro-syenite complex in the North Carolina piedmont, Olsen and McSween (1983) document plagioclase compositions ranging from $An_{31.77}$ in the gabbros. In the syenites, groundmass plagioclase ranges in composition from An ₁₋₁₆. Butler and Ragland (1969) and Olsen and McSween (1983) concluded that the Concord syenite was a differentiation product of associated gabbroic intrusions. Published data from the Concord gabbro-syenite suite and the Dutchman's Creek gabbro contain very limited microprobe data, but if conclusions regarding the consanguinity of the gabbro and associated syenite are correct, an exhaustive study of plagioclase compositions in the suite should form a continuum of compositions between the end members reported. Enclave plagioclase in the Danburg could thus be of similar composition to plagioclase formed along a portion of the gabbro- syenite differentiation trend.

In enclaves from the Mefantic Complex granites, Bedard (1990) reported a range of plagioclase compositions from oligoclase to albite. These are similar to plagioclase in the

Danburg pluton enclaves, and again suggest the possibility that in the Danburg pluton, the enclave magma may be more alkalic in nature.

Amphibole compositions are considered sensitive indicators of magma composition. When the normative compositions of Danburg enclave are plotted within the basalt tetrahedron, they plot in an area of the *ne-Q-cpx* plane which Cawthorne (1976) suggests is characteristic of amphiboles crystallized in mildly silica undersaturated magmas. In this same plane of the tetrahedron, amphiboles from enclaves in Sierra Nevada batholith rocks (Dorais, 1987) are more characteristic of a magma with a higher degree of silica undersaturation. Amphiboles from the Dutchman Creek gabbros of South Carolina (McSween and Nystrom, 1979) and the Concord suite of North Carolina (Olsen and McSween, 1983) are extremely limited in number (two analyses from each area). Nonetheless, they are also closer in composition to those of alkaline provinces. One exception is a single analysis from the Dutchman Creek rocks, which is similar in composition to the Danburg enclave amphiboles. This at least raises the possibility that the Danburg enclave amphiboles may resemble those from nearby rocks associated with gabbros and syenites.

Hybridization and Enclave Formation

The degree to which intermingling magmas will mix is dependent upon the temperature and viscosity contrasts between the two liquids (Sparks and Marshall, 1986). This, in turn, is largely controlled by bulk composition. A granitic magma which is cooler than an underplating basaltic magma can cause complete quenching and the formation of globules of the underplating basalt. Given a lesser temperature contrast, the underplating magma may quench to a mixture of crystals and residual liquid. The degree

to which the granitic magma and the residual liquid will mix is then variable, depending on density and viscosity differences. The zone of hybridization can produce a variety of enclave compositions and textures dependent on the amount of quenched crystals, the composition of the residual liquid, and the relative proportions of the two end members.

The common ocelli- type textural variety of Danburg enclave is rare in granitoids, and to my knowledge has only been described in the literature by Hibbard (1991) in a small Mesozoic stock near Austin, Nevada, and by Baxter and Feely (2002), and neither author reports any chemical data. Hibbard (1991) suggested that these ocelli enclaves formed in a two stage mixing process. In this model, a Ti- rich mafic liquid mixes with a granitic liquid, resulting in crystallization of titanite and plagioclase in ophitic relation. This hybrid system then equilibrates, resulting in crystallization of potassium feldspar +/quartz. These clots of crystals are then disaggregated as the equilibrated hybrid system mixes with mafic melt a second time. It is this second mixing event which produces the biotite- rich groundmass surrounding the titanite-plagioclase ocelli. In the Danburg pluton I suggest a similar model for the ocelli type enclaves. In these enclaves, the titanite centered within each ocelli is in ophitic relation with small laths of relatively calcic plagioclase (An_{25} average) or potassium feldspar, but rarely both. The ocelli are interpreted to have formed early, as a relatively mafic, Ti- rich magma the more mafic was quenched in the Danburg magma. This created an initial hybrid magma, which, as it continued to crystallize, precipitated less calcic plagioclase, quartz, and perhaps potassium feldspar around the ocelli. The overall dominance of one feldspar group within individual ocelli, and indeed sometimes within the enclave as a whole, suggests the hybrid system was inhomogeneous. Following initial quenching and crystallization

of the ocelli, this hybrid magma was then mixed with another more mafic magma. This resulted in the precipitation of hydrogenic (blade) biotite in a new hybrid system represented by the biotite rich region that surrounds the ocelli. The occasional occurrence of wispy, cuspate-lobate margins of the biotite rich zone (Figure 3-7) indicates that this zone was still dominantly liquid at this stage. Intriguingly, similar titanite-cored feldspar occurs sparsely in some Elberton granite samples (M. Roden, pers. comm.).

The gradational continuum observed between ocelli enclaves and coalesced enclaves is interpreted to reflect a continuum of disaggregation of the hybrid system. In the outcrop, this is reflected by a variable degree of contrast between the ocelli and the biotite- rich inter- ocelli zone. Eventually the ocelli become indistinguishable, and the enclaves become more leucocratic. Where this process was allowed to proceed most completely, highly coalesced enclaves were produced which range in composition from syenitic to granodioritic.

The origin of the microgranitoid enclaves is more difficult to evaluate in the context of this model. Their quench textures are not as strongly pronounced, they are relatively equigranular, and their grain size is larger than in other enclaves, although still much smaller than the grain size typical of the Danburg pluton. The microgranitoid enclaves have SiO_2 contents intermediate between those of the ocelli and coalesced enclaves, although they have major and trace element contents comparable to the ocelli enclaves.

Textural considerations require that the microgranitoid enclaves were not as severely undercooled as the ocelli enclaves. Several possibilities arise concerning their formation, namely: (1) They may represent a second and distinct batch of intermingling magma, which was at a temperature similar to that of the Danburg magma. However, the presence of limited quench textures still requires a degree of undercooling sufficient to produce them.

(2) A fresh batch of more mafic magma was mingled in the zone of hybridization; the smaller temperature contrast could then allow the growth of larger crystals.

(3) The coarser crystals in the microgranitoid enclaves might represent material that crystallized in the mafic system prior to being injected into the Danburg magma. This hypothesis is supported by the larger crystal size observed in the microgranitoid variety, particularly for plagioclase. However, enclaves formed from a crystalline mush precipitated from the mafic magma prior to mixing are usually characterized by the presence of anhydrous phases common on the liquidus of mafic magmas (i.e. pyroxene, olivine) (Orsini et al., 1991; Orsini, 1979; Zorpi, 1988; Cocirta et al., 1989). None of the enclaves in the Danburg pluton preserve such parageneses, hence the microgranitoid enclaves can not represent pre-mixing crystallization products of the mafic system.

(4) These enclaves might represent residual liquids produced during a quenching event related to the ocelli enclaves. The residual liquid could then be removed from the hybridization zone and allowed to cool. Seaman and Ramsey (1992) concluded that certain texturally distinct enclaves in the Cadillac Mountain granite of Maine formed by a similar mechanism. As is the case in the Danburg pluton, they documented different textural varieties of enclaves, including one type that was very similar to the microgranitoid enclaves in the Danburg (Seaman and Ramsey, 1992, p.402). In both cases, the microgranitoid enclaves (termed "pegmatitic pods" by Seaman and Ramsey) contained the same mineral species as the host granite, differing only in the proportions of each mineral phase. They were able to document blobs of the coarser grained enclave material marginal to finer grained enclaves, connected by a trail of coarser grained material between the two enclave types. They concluded that the finer grained enclaves, upon crystallization, produced an H_2O -rich residual melt that then migrated out of the fine-grained enclave along crystal boundaries. The excess H_2O vapor in the migrating material enhanced diffusion to the point that coarser crystals were formed, similar to the process recognized in pegmatites. In the Danburg enclave suite, similar connecting trails of material have not been observed linking the microgranitoid enclaves to other textural varieties, but a similar process is proposed here for their formation. Eichelberger (1980) has calculated that upon crystallization, an enclave can evolve fluid up to an order of magnitude more abundant than present in the original basaltic melt. This fluid enhanced crystallization can explain the similar chemistry of the microgranitoid enclaves. The SiO₂ contents of microgranitoid enclaves are intermediate between those of the ocelli $(SiO_2 \text{ poor})$ and coalesced (highest SiO₂) enclaves. This would require the microgranitoid enclaves to have evolved from the ocelli variety only, since any residual liquid produced upon crystallization of a particular enclave variety would necessarily be more SiO_2 rich than the parent liquid.

The question still remains as to whether more than one mafic magma was involved in the formation of the enclave population. In a study of enclaves and host rocks in four separate intrusions comprising the Corsican-Sardinian calc-alkaline batholith, Orsini et al. (1991) demonstrated that the FeO (total) / MgO ratio of enclaves remain relatively constant within any given pluton. They concluded that this ratio is essentially unaltered during enclave formation and is inherited from the basaltic magma responsible for
enclave generation, prior to mixing. FeO (total) / MgO ratios in the Danburg enclaves (Figure 4-7) show a limited amount of variation, and this supports a model whereby the various enclaves were formed from a unique and single mafic parent magma, although multiple injections of this magma are plausible. The relatively small degree of variation in FeO (total) / MgO but large variation in SiO₂ could be explained by fractionation processes in the mafic parent prior to mixing with the Danburg magma. This argues for a chemical or mechanical mechanism responsible for the formation of the different enclave varieties, without having to invoke multiple magmas being mingled with the Danburg. <u>Summary and Conclusions</u>

Enclaves in the Danburg pluton formed by quenching of a relatively mafic liquid against the Danburg magma. On textural arguments, the least evolved enclaves appear to be the ocelli type. These can be shown in the outcrop to grade into the coalesced type of enclave. The microgranitoid variety may be from the same hybrid magma that crystallized the ocelli enclaves, but having crystallized under more H₂O-saturated conditions. Whole rock chemical data suggest that the suite formed by mingling, with concomitant crystallization of feldspars and biotite controlling their major element chemistry. Mingling between felsic and mafic liquids or crystal mushes produced coherent linear arrays on mixing lines which are sensitive to feldspar and biotite crystallization. Trace element variation appears to have been more erratic. This likely resulted from some combination of (1) variable redistribution of trace elements by residual melts and exsolved volatiles, and (2) inconsistent efficiency of mechanical separation of accessory minerals. Although a basaltic parent to the enclaves cannot be ruled out, comparison of the data with other enclave suites favors a parent magma with elevated trace element abundances, such as an alkaline or peralkaline gabbroic differentiate. The spatial association of the Danburg pluton and a small adjacent body of syenite support this possibility. Sparse occurrences of outcrop textures in the adjacent syenite (Figure 4-8) strongly resemble hybridization textures in certain Danburg enclaves. Putting aside questions about the peralkalinity of the parent enclave melt, the enclaves themselves are very different in composition from the majority of enclaves in the literature. Their bulk rock chemistry and elevated trace element abundances indicate a different genesis than most enclaves found in compressional margin settings.

Figure 4-7. MgO vs. $Fe_2O_3(t)$ in mafic enclave suite. MgO vs. total Fe (as Fe_2O) showing the minor variation in this ratio within the population of enclaves in the Danburg pluton. Symbols are as in Figure 10 (asterisks = ocelli; open diamonds = microgranitoid; crosses = coalesced; open circles = Sandy Hill granite; filled circles = Danburg pluton)



Figure 4-8. Possible magma mixing textures in the Delhi syenite. Hand sample photographs comparing the hybridization textures typical of coalesced enclaves in the Danburg pluton (top photo) with textures observed (although rarely) in the small Delhi syenite body in contact with the western edge of the Danburg pluton.





CHAPTER V: ORIGIN OF THE DANBURG AND SANDY HILL PLUTONS

Introduction

Chemical data from the Danburg and Sandy Hill bodies is presented in Chapter 3. The petrology and origin of the mafic enclaves is discussed in the previous chapter. The purpose of this chapter is to review salient points concerning the chemistry, and to interpret this data as to how it reflects the evolution of the Danburg and Sandy Hill plutons. Rb-Sr isotopic data is also reviewed and interpreted, and the age of the Danburg pluton is presented. Finally, the data are evaluated in terms of how they may influence the debate over the specific tectonic setting in which the rocks formed.

Major and Trace Element Chemistry

The study of the chemical evolution of silica-rich volcanic rocks is relatively straightforward, partly because samples representing liquid compositions are sometimes available. Conversely, coarsely crystalline plutonic rocks are more difficult to evaluate for several reasons, some of which are described below.

First, the coarsely crystalline nature and high viscosity associated with melts of this composition make it difficult to sample areas representative of liquid composition. These same properties also render crystal-liquid reactions somewhat sluggish (Hanson, 1978), so that geochemical modeling is hampered. Second, it is difficult to sample and prepare a sufficient volume of coarsely crystalline rock to assure that a homogenous split, representative of the entire whole rock volume, can be isolated. These difficulties should be acknowledged prior to interpreting the physical processes responsible for forming these rocks.

Major Elements

On the basis of total alkalis versus silica, the Danburg and Sandy Hill granitoids are

subalkaline, although some of the Sandy Hill rocks approach mildly alkaline compositions. By the same measure (total alkalis versus silica), the Danburg rocks are classified as true granites, whereas the Sandy Hill rocks are mostly alkali granites. The granitoids are mostly metaluminous by the terminology of Shand (1951). Some of the Sandy Hill rocks, and one or two samples of the Danburg pluton, straddle the metaluminous-peralkaline boundary. Also, one sample of the Sandy Hill granite, and the fine grained tonalitic phase of the Danburg, plot as weakly peraluminous. In the case of the tonalitic sample from the Danburg, this likely reflects the high modal percentage of biotite in this particular sample.

Most major oxides show a linear or curvilinear decrease with increasing silica (Figure 5-1). These relationships are consistent with fractionation of feldspars, magnetite, and the accessory minerals apatite and titanite. CaO contents decrease with increasing silica, as would be expected with fractionation of plagioclase. Data for K₂O and Na₂O show considerable scatter. Na₂O concentrations, however, actually appear to decrease with increase with increasing silica. Due to a constant sum effect, the overall inverse relationship between CaO, the alkalis, and silica probably reflects dilution due to an increase in the modal abundance of quartz. Field observations substantiate the local variation in modal abundance of quartz.

Note that the sum of the alkalis is generally constant over the observed range of silica. Speer and Hoff (1997) interpreted a similar pattern in other Alleghanian granitoids to reflect an actual increase in alkalis, given the competing effects of dilution of the major elements as modal quartz increases. The inverse relationship between silica and P_2O_5 , TiO₂, and total FeO (as Fe₂O₃) is quite pronounced. In addition to dilution by quartz,

these patterns likely also reflect fractionation of apatite, titanite, and magnetite, respectively.

Trace Elements

Negative slopes on silica variation diagrams (Figure 5-2) also characterize most trace element variations. The one clear exception to this is Ba, which is positively correlated with SiO_2 in the Danburg pluton. Silica variation diagrams of some trace elements show considerable scatter. The elements V, Rb, Sr, Zr, and Ba display relatively coherent variation. Nb has no clear correlation with SiO_2 .

Effects of crystal fractionation of titanite are seen in the decreasing abundance of TiO_2 and all REE except Yb and Lu. Magnetite fractionation is also reflected in decreasing abundances of total Fe and V. Zirconium abundances in the more SiO_2 -poor portions of the Danburg pluton decrease from just above 300 ppm to approximately 250 ppm, which likely reflects fractionation of zircon. Zr abundances are relatively constant in samples with 71% SiO_2 or greater. One exception to this is a single sample at 72.5% SiO_2 , which, on the basis of elevated Zr and Hf concentrations, may contain cumulus zircon.

Bivariate plots of Rb, Sr, and Ba are useful in identifying fractionation of feldspars. Figure 5-3 shows variation of Sr with respect to Rb (upper diagram) and Ba (lower diagram). Generalized vectors representing compositional trends produced by Rayleigh fractionation of single phases are taken from Speer and Hoff (1997). In the Rb vs. Sr plot, the Danburg and Sandy Hill samples define a trend of decreasing Sr with increasing Rb. In contrast, Ba and Sr concentrations are positively correlated, and both are present in relatively high abundances in the Danburg rocks. Both relationships are consistent with fractionation of alkali feldspar coupled with subordinate amounts of plagioclase, although fractional melting of a feldspar-rich source could cause similar variation. Effects of plagioclase fractionation are also seen in Figure 5-4, where the CaO/Ba ratio is at a maximum in the fine-grained tonalitic sample from the Danburg. This value drops sharply as SiO2 increases, but the remainder of the trend is characterized by a gentler decrease in the CaO/Ba ratio. Thus, fractionation of plagioclase seems to have been important early in the evolution of the pluton, and assumed a less dominant role as the magma became more silica-rich.

Normalized trace element abundances are presented in Figure 5-5a and 5-5b. Relative depletions of some trace elements can be attributed to crystal fractionation of minerals that incorporate these elements. For example, feldspar fractionation is evidenced by negative anomalies of Ba and Sr. Fractionation of titanite and Fe-Ti oxides is indicated by depletions in Ti, Y, and V, while depletion of P is consistent with fractionation of apatite. Zirconium is only mildly depleted in these plots, and suggests that large amounts of zircon fractionation did not occur.

Negative Ta and Nb anomalies are typical of subduction zone volcanic rocks (Arculus, 1987; Karabinos et al., 1998; Condie, 1989; Wilson, 1989). The near constant Nb concentration in the Danburg and Sandy Hill samples may indicate that the Nb and Ta anomalies (Figure 5-5) are independent of crystal fractionation processes in the Danburg and Sandy Hill rocks, and hence this Nb-Ta depletion may be a source characteristic.

Figure 5-1. Major element variation in granitic rocks. Silica variation diagrams of selected major elements from the Danburg pluton (filled circles), Sandy Hill granite (open circles) and mafic schlieren from the Danburg pluton (filled triangles).





Figure 5-2. Trace element variation in granitic rocks. Silica variation diagrams of selected trace elements from the Danburg pluton (filled circles), Sandy Hill granite (open circles) and mafic schlieren from the Danburg pluton (filled triangles).





Figure 5-3. Log-log plots of Ba vs. Sr and Rb vs. Sr. Lines represent generalized paths of liquid compositions undergoing Rayleigh fractionation of single phases (from Speer and Hoff, 1997).





Figure 5-4. SiO_2 vs. CaO/Ba in granitic rocks. Danburg pluton (filled circles), Sandy Hill granite (open circles) and mafic schlieren from the Danburg pluton (filled triangles). The Danburg sample with the lowest SiO₂ and higherst CaO/Ba values is the fine grained tonalitic sample (DG2fg).



Figure 5-5a (first page) and 5-5b (second page). Normalized trace element plots from granitic rocks. Average compositions of the Danburg pluton (solid circles), Sandy Hill granite (open circles), and a single analysis of the Danburg pluton aplite (asterisks). Figure 5-5a is normalized to upper continental crustal values from Taylor and McLennan (1985); Figure 5-5b is normalized to the chondritic values from Thompson (1982);





Rare Earth Elements

REE abundances were determined for a coarsely crystalline Danburg sample, one aplite from the Danburg pluton, and one coarsely crystalline sample from the Sandy Hill granite. Additionally, REE abundances were measured in a mafic schlieren from the Danburg, and in titanite separates from both the Danburg pluton and a mafic enclave. Chondrite normalized REE plots using the normalization constants of Nakamura (1974) are are presented graphically in Figure 5-6.

All chondrite normalized patterns from these rocks are characterized by moderate slopes with La/Lu]_N ratios of 32 in the Danburg granitoid, 28 in the mafic schlieren, and 19 in the aplite. Titanite separates are highly enriched in all REE, but show less fractionated patterns with $La/Lu]_N = 7$. All samples, both whole rock and mineral separates, show small to moderate negative Eu anomalies, indicating that fractional crystallization of feldspar, or the retention of feldspar in the source region, played some role in their genesis. In either case a significant crustal component was involved in magma genesis. The parallelism between titanite separates and whole rock samples indicates that the overall whole rock REE patterns are dominated by titanite. Such dominant control of REE patterns by one mineral species makes it difficult to use the REE plots to evaluate other processes in the evolution of the rocks. Garnet appears unlikely to be involved in the source residue. Since partition coefficients for the HREE in garnet are approximately 100 times those for the LREE (Hanson, 1978 and references therein), the REE patterns for the rocks in this study are probably not steep enough to indicate garnet in the source residue. This argues against high pressure melting of a basaltic source.

Hornblende, although a minor constituent in the rocks of this study, also appears to have exerted significant compositional control. Speer and Hoff (1997) suggested that much of the major element differences between Alleghanian granitoids could be explained by fractionation of hornblende, or by the presence of residual hornblende during melting. They based this conclusion on the compositional trend of these rocks when plotted on an AFM diagram; most Alleghanian granitoids produced an array of compositions that lies between two lines radiating away from hornblende. The Danburg rocks generally follow this same trend. Additionally, hornblende concentrates the middle REE (Arth, 1976; Green and Pearson, 1985), thus residual hornblende should result in relatively low abundances of the middle REE in the melt. Partly on the basis of a similar REE pattern they obtained from the Danburg pluton, Whitney and Wenner (1980) suggested that the pluton was consistent with derivation from an amphibolitic lower crust. They suggested an original magma formed by 10% to 20% melting of metagabbroic rocks, with retention of hornblende and plagioclase in the source area. Data from this study are consistent with their conclusions.

The Danburg aplites have relatively low abundances of LREE compared to their host rocks, as is typical of many aplite-granitoid pairs (Noyes et al., 1983). As it is generally agreed that the LREE behave as compatible elements during the last stages of silicic magma evolution (Mittlefehldt and Miller, 1983; Noyes et al., 1983), their relative depletion in melts that formed the aplites is possibly due to the fractionation of LREE-rich minerals such as allanite or monazite (Noyes et al., 1983).

Figure 5-6 Chondrite-normalized REE plots of granitic rocks. REE diagram for the Danburg pluton (solid circles), Sandy Hill granite (open circles), Danburg pluton aplite (asterisks), mafic schlieren (solid triangles), and titanite from the Danburg pluton (open diamonds).



Rb-Sr Isotope Geochronology

One goal of the study was to determine the precise age and initial ratio of the Danburg pluton and enclaves. Analytical procedures are described in Chapter 3. A discussion of the results is presented below.

⁸⁷Rb/⁸⁶Sr ratios within the Danburg pluton are somewhat restricted, ranging from 1.23 to 2.25 (Table 5-1). In contrast, four samples of the Sandy Hill granite have ⁸⁷Rb/⁸⁶Sr values ranging from 1.98 to 71.4. If all analyses are regressed as a single data set, an 'isochron' yields an age of 295 Ma with a r^2 value > 0.998. When regressed using the algorithm of York (1969), the data are resolved into two separate and subparallel isochrons. Ages and initial ratios calculated from the Danburg pluton alone $(307 \pm 7 \text{ Ma})$; $Sr_i = 0.7048 \pm 0.0002$) versus those from only the mafic enclaves (303.8 \pm 0.4 Ma; $Sr_i =$ 0.70471 ± 0.00001) are indistinguishable within analytical error. Regression of the Danburg granite mafic enclaves alone yields an isochron of age 304 ± 5.4 Ma and an initial ratio of 0.7048 \pm 0.0002. Sandy Hill granite samples alone yield an age of 294 \pm 9 Ma and an initial ratio of 0.70716 ± 0.00005 . While both granites have ⁸⁷Sr/⁸⁶Sr ratios consistent with typical Caledonian-style I-type granitic rocks and suggestive of a chemically unevolved lower crustal source, the Sandy Hill granite has a distinctively higher initial ratio. Additionally, during the time interval between generation of the two plutons, the Danburg granite (or its plausible source residue) could not have evolved sufficiently to yield the more radiogenic initial ratio of the Sandy Hill granite (Figure 5-7). Thus, a second melting event involving the Danburg granite itself, or of its source region, cannot be invoked to explain the origin of the Sandy Hill granite. The calculated

age for the Sandy Hill granite should be considered suspect because of feldspar sericitization, and it should not be included in the database of existing Rb-Sr pluton ages. I believe the most reliable age obtained in this study is derived by combining the Danburg granite and the mafic enclaves $(304 \pm 5 \text{ Ma}; {}^{87}\text{Sr}/{}^{86}\text{Sr}]_i = 0.7048 \pm 0002)$ (Figure 5-8). This isochron was derived using the algorithm of Ludwig (2000), and differs from the York algorithm in that errors are more rigorously treated, following the error propagation algorithm of Titterington and Halliday (1979). Consequently, reported errors are greater than those calculated by the York (1969) algorithm, but are considered to be more realistic. The Ludwig algorithm returned a probability of fit near zero for the classical Model 1 (York) isochron. Thus, a Model 3 fit was used, which assumes the scatter observed is due to a combination of the reported analytical errors and an unknown but normally distributed variation in the ⁸⁷Sr/⁸⁶Sr values. Ludwig (2000) suggests a common reason for this is variation is an isotopically inhomogeneous source area. Given the variety of rock types exposed within and around the Danburg pluton, this assumption is most likely valid.

Other parallel isochrons have been reported from the southern Appalachians (Ellwood et al., 1980; Fullagar and Butler, 1976; Butler and Fullagar, 1978; Mose and Wenner, 1980). For example, Ellwood et al., (1980) reported two sub-parallel Rb-Sr isochrons from the Elberton granite, 25 km northwest of the study area. One of these isochrons (350 ± 11 Ma; 87 Sr/ 86 Sr = 0.7037 ± .0005) was derived from samples free of alteration and not proximal to metamorphic wallrock xenoliths. The second isochron was derived from samples close to areas exhibiting hydrothermal alteration or having an abundance of wallrock xenoliths. Although the two ages are statistically

Figure 5-7. Age vs. initial ratios of selected southern Appalachian granites. Reasonably well-constrained ages and initial Sr ratios of Alleghanian plutons in the Carolina terrane of the southern Appalachians. Sources of data are: (1) Siloam pluton (Jones and Walker ,1973); (2) Pageland pluton (Fullagar and Butler, 1979); (3) Winnsboro pluton (Fullagar, 1971); (4) Danburg pluton, this report; (5) Clover pluton (Fullagar and Kish, 1981) and (6) Pee Dee quartz norite (Kish, 1983).



Table 5-1. Rb-Sr isotopic determinations used for isochron plot. Isotope ratios and 2 sigma errors used to calculate isochron parameters.

		<u>ppm Rb</u>	<u>ppm Sr</u>	87Rb/86Sr	$\frac{87}{3}$ Sr/ $\frac{86}{3}$ Sr
Danburg	DG2fg	151	325	1.33	0.71077 ± 0.00005
<u>granite</u>	DG310/2f	145	210	2.25	0.71461 ± 0.00005
	DG201	171	371	1.33	0.71060 ± 0.00007
	DG89	177	363	1.41	0.71085 ± 0.00005
	DG106	161	333	1.40	0.71078 ± 0.00005
Mafic	105En	165	321	1.59	0.71157 ± 0.00004
enclaves	305En.2	167	294	1.79	0.71245 ± 0.00010
	309En.WR	166	373	0.71	0.70779 ± 0.00007
	E-U-5 avg	327	245	3.85	0.72136 ± 0.00006

Figure 5-8. Rb-Sr isochron plot of the Danburg rocks. Plot includes data from the granitoids and the mafic enclaves. All errors are 2 sigma. Data used is presented in Table 5-1.



indistinguishable, the isochron derived from altered areas of the pluton had a high error $(376 \pm 45 \text{ Ma}; {}^{87}\text{Sr}/{}^{86}\text{Sr} = 0.7054 \pm 0024)$. This was interpreted by the authors to reflect wallrock contamination or an isotopically inhomogeneous source area. Additionally, Fullagar and Butler (1976) reported parallel isochrons from the Sparta complex, about 50 km south of the Danburg pluton, which has since been shown to consist of multiple injections of chemically distinct and non-cogenetic melts (Speer et al., 1980; Whitney and Wenner, 1980). While either of these scenarios may provide a plausible explanation of the parallel Sandy Hill isochron, the degree to which feldspars are sericitized in the Sandy Hill rocks necessitates treating the Sandy Hill isochron data with caution. Physical Conditions of Crystallization and Emplacement

Pressure and temperature of crystallization were calculated using the amphiboleplagioclase thermometer of Holland and Blundy (1994) and the amphibole-plagioclase qtz-mt-ksp barometer of Anderson and Smith (1995). Results are given in Table 5-2 and presented graphically in Figure 5-9.

Whitney and Stormer (1977) applied the 2-feldspar geothermometer of Stormer (1975) and Whitney and Stormer (1977) to the Danburg pluton, which is based on the distribution of NaAlSi₃O₈ between co-existing alkali feldspar and plagioclase. Their results indicated a crystallization temperature of 776°C (cores) to 706°C (rims) and an inferred pressure of 1.5 to 2 kbar, based on the quartz monzonite solidus of Whitney (1975), and consistency with regional tectonic relationships and mineral stabilities. A lack of barometric indicator minerals in adjacent rocks has precluded quantitative estimates of pluton emplacement pressures. This study combines the amphibole-plagioclase thermometer of Holland and Blundy (1994), accurate to within \pm 40 °C, with
the barometer of Anderson and Smith (1995), sensitive to within ± 0.6 kbar. Reported accuracy and precision do not account for normal microprobe analytical errors unique to this study. These data indicate a similar crystallization temperature but add a quantitative estimate of crystallization pressures.

All mineral compositions were measured at mineral rims, either from crystals in direct contact, or from nearby crystals where no evidence of textural disequilibrium was evident. The amphibole recalculation scheme follows that of Holland and Blundy (1994), which assumes 13 cations excluding Na, K, and Ca, and has an improved procedure for allocating ferric iron, which has been shown by Cosca et. al. (1991) to influence pressure calculations. Amphibole compositions are consistent with true igneous amphiboles, and in conjunction with their sub- to euhedral textures, are interpreted as true magmatic phases.

Pressure and temperature are calculated from plagioclase - hornblende pairs in both the mafic schlieren (sample DG 202), interpreted as an early crystal cumulate, and from the coarsely crystalline phase of the Danburg granite (sample 101AX). As quartz is present in all samples, the calibration 'A' of Holland and Blundy (1994) is used for temperature calculations. Not listed in Table 5-2 are similar calculations made from the same mineral paragenesis in the mafic enclaves. Enclave pressures and temperatures are indistinguishable from those derived from the granitic rocks, when analytical error is taken under consideration. This is not interpreted as reflecting the temperature of the enclave magma, but rather to be indicative of the overall degree to which the enclave magma chemically equilibrated with the Danburg magma. Figure 5-9. Amphibole-plagioclase thermobarometry. Mineral rim pressures and temperatures (see text for discussion) plotted in PT space. A typical tonalite solidus and the quartz monzonite solidus of Whitney (1975) are shown for reference. Triangles are data from the mafic schlieren; circles are data taken from the coarsely crystalline portion of the Danburg pluton.



Table 5-2. Summary of amphibole-plagioclase thermobarometry results. Pressures and temperatures calculated from the amphibole-plagioclase thermometer of Holland and Blundy (1994), and the amphibole barometer of Anderson and Smith (1995). Sample 202 is a cumulate mafic schlieren,; sample 101XA is a granitoid immediately adjacent to mafic enclaves

Sample	T (oC)	P (kbar)	Average T	Average P
202 a	768	4.1	-	-
202 b	776	3.6	778	3.8
202 c	790	3.6		
101 XA a	765	4.0		
101 XA b	756	3.6		
101 XA c	746	3.8		
101 XA d	773	3.9	759	3.9
101 XA e	783	3.8		
101 XA f	747	3.9		
101 XA g	754	4.2		
101 XA h	744	4.2		

Calculated pressures and temperatures derived from the mafic schlieren and from the granitic rocks are indistinguishable within analytical error. An average of several calculations yields a temperature of 768 °C and a pressure of 3.8 kbar. These figures are consistent with data reported by Vyhnal et al. (1991), when recalculated by the same method used in the Danburg rocks, and are only a few degrees higher than earlier estimates published by Whitney and Stormer (1977). The data indicate that early crystallization of the magma took place a few tens of degrees above a typical tonalite solidus. The euhedral nature of the amphibole and plagioclase support this argument. The higher pressures indicated in this study, as compared to Whitney and Stormer (1977), arise from their estimate of pressure being largely an emplacement pressure, whereas these data indicate early crystallization conditions. If the emplacement pressures of earlier estimates are correct, the magma underwent magma mixing at depth of approximately 12 km and rose considerably prior to final solidification and emplacement. Indeed, flow foliation in the Danburg pluton indicates that it rose prior to complete solidification.

Relationship Between the Sandy Hill and Danburg Plutons

The Sandy Hill granite comprises an envelope of leucocratic granite on the southern and southeastern margin of the Danburg pluton. The precise contact between the two bodies is buried; thus their field relationships are unclear. The finer grained texture of the Sandy Hill granite would be compatible with it being generated as a marginal, chilled phase of the Danburg pluton as the latter crystallized from the outside inward. Alternatively, the Sandy Hill may be a remnant of an older pluton intruded by the Danburg, or, a younger melt that ascended along the margin of the Danburg pluton; this last relationship is consistent with the Rb-Sr isochron data discussed. In the latter case, the Sandy Hill may comprise a second melting event unrelated to the Danburg pluton, or it may represent residual, SiO_2 -enriched late crystallization products from the Danburg.

Similar, fluid-enriched melts have been modeled by Whitney (1975). As a crystallizing magma evolving a fluid phase is disrupted by movement through the crust, portions of the magma which have reached vapor saturation can expel a fluid rich phase which collects near the edge of a molten body. The result would be an envelope of late stage crystallization products similar to that represented by the Sandy Hill granite.

Certain compositional trends linking the Danburg and Sandy Hill bodies are compatible with such an origin. For example, plagioclase compositions in the Sandy Hill are generally more albitic than in the Danburg, although there is considerable overlap. Major element abundance trends defined by the Danburg rocks are continued uninterrupted by the Sandy Hill rocks into higher SiO₂ portions of variation diagrams. Most trace elements behave in identical fashion, with the exceptions of Rb and Sr, and, to a lesser extent, Y and Ba. In some cases, Sr and Ba are severely depleted relative to the Danburg rocks, whereas Sandy Hill rocks are highly enriched in Rb relative to the Danburg pluton. This behavior is compatible with removal of mobile elements by a vapor saturated phase expelled from the Danburg. The increased scatter seen in the Sandy Hill data, especially that of trace elements, could be explained by remobilization into this fluid rich melt. The Sandy Hill rocks have suffered deuteric alteration to an extent not seen in the Danburg rocks, which would be expected under such a scenario as outlined above. Nonetheless, it is problematic that other hydrothermally mobile elements in the Sandy Hill rocks are not as remobilized as are others.

Finally, the magnitude of the negative Eu anomaly in the Sandy Hill rocks is greater than in the Danburg, and the two bodies have otherwise similar REE patterns This is consistent with the Sandy Hill magma having been produced after continued fractionation of plagioclase from the Danburg melt.

Interpreting the Sandy Hill as late-stage, fluid enriched products of the Danburg magma poses at least three problems. First, although scatter in the data are compatible with such a process, Rb variation in the Sandy Hill rocks is quite coherent with respect to silica. As Rb is considered highly mobile under such conditions, this coherence seems unexpected. Second, there is considerable overlap in plagioclase compositions between the two plutons. And finally, the different initial ratios do not support such a model. Thus, it is proposed that the Sandy Hill rocks represent a small volume of approximately contemporaneous magma which was generated from a source with different chemical and isotopic characteristics than the Danburg source region.

Geochemical Indicators of Tectonic Setting

These data have three potential contributions to the debate over the tectonic setting of the Laurentian margin during the Alleghanian orogeny. First, a precise age and ⁸⁷Sr/⁸⁶Sr initial ratio add to a sparse database of similar data. Second, elemental data allow comparison to plutons of known tectonic setting. Third, the same data allow comparison with the extensive compilation of Speer and Hoff (1997) of southern Appalachian Alleghanian plutons.

The ubiquitous occurrence of the mineral assemblage titanite + magnetite \pm hornblende reflects a relatively oxidized source. The Danburg pluton has an ε_{sr} value (+9.9) broadly compatible with those from post-collisional uplift regimes, which are

considerably higher than those associated with pre-collisional continental margin arcs (Harris et al., 1986). Furthermore, an ε_{Nd} value of (-1.7) (Samson et al., 1995), even when recalculated using an age of 303 Ma (ε_{Nd} , 303 Ma = -1.5), argues for a subordinate mantle component in the Danburg magmatic system, again arguing against a subduction zone origin.

Elemental data are ambiguous in this respect. The average molar A/CNK value of Danburg samples (0.96) is characteristic of both Caledonian and Cordilleran I-type granites (Pitcher, 1982). Commonly used discrimination diagrams involving Rb, Nb, and Y (Pearce et al., 1984) suggest a volcanic arc environment, which includes active continental margin arcs. This approach suffers from the highly mobile nature of Rb. Discrimination on the basis of Hf, Ta and Rb (Harris et al., 1986) is potentially more useful, as this method can differentiate late and post-collisional granites from those formed in the volcanic arc and continental margin settings. However, in addition to the problem of Rb mobility, the present study lacks sufficient Ta and Hf data to characterize the pluton in this respect.

In contrast, extended REE diagrams show strong Ta and Nb depletion and elevated LIL concentrations. Many authors have cited similar data as a key subduction zone signature (e.g. Briqueu et al., 1984; Arculus, 1987; Karabinos et al., 1998; Condie, 1989; Wilson, 1989) for felsic rocks formed in volcanic island arcs similar to the Carolina terrane. REE patterns also show moderate Eu depletion, indicating fractionation of plagioclase must have occurred. The latter indicates an important involvement of a crustal source or process, although this is common in subduction zone settings too.

In summary, major and trace element data suggest the Danburg pluton has subduction-related affinities. Isotopic data, which are perhaps the most rigorous criteria, suggest the pluton formed in a post-collisional environment where crustal source rocks were dominant, although they are also permissive of a subduction zone origin. Again, the relative abundances of granitoids, gabbroids, and intermediate plutonic rocks is not consistent with the roots of a magmatic arc produced above a subduction zone. Geochemical signatures such as Ta and Nb depletion and elevated LIL contents may be inherited from the source region, due to stabilization of ilmenite in the source residue, or the involvement of a fluid phase not related to slab de-watering. If only tightly bracketed ages and initial ratios of Alleghanian plutons in the Carolina terrane are considered (Figure 5-7), younger plutons are characterized by higher initial Sr ratios. Similar trends have been noted in the Inner Piedmont and Blue Ridge of the Carolinas (Fullagar et al., 1979) and in the Siluro-Devonian plutons of the Charlotte belt in the Carolina terrane (Sinha et al., 1989). This argues for a proportionally greater contribution from a crustal component through time, between ca. 260-325 Ma. This, in turn, argues against the relatively constant addition of juvenile crust expected above an active subduction zone. These ambiguities, coupled with the lack of voluminous plutonism and compositional diversity observed in known subduction settings, suggest the Danburg pluton formed in response to post-subduction collisional uplift. The geochemical signatures indicative of subduction are therefore interpreted as most likely inherited from the earlier history of the source region.

CHAPTER VI: CONCLUDING REMARKS

The age of the Danburg pluton (304 +/- 5 Ma) is among the older of the precisely dated Alleghanian plutons. Within any given pluton, if one compares a published Rb-Sr age with U-Pb ages, it is not uncommon to see that the U-Pb age is older. As many of the Alleghanian plutons were dated some time ago by Rb-Sr methods, newer work seems to have pushed back the time frame in which many of these rocks formed. The tectonic implication of any of these ages is, of course, dependent on the mechanism responsible for pluton generation. Given the nature of much of the current thinking about the genesis of Alleghanian plutons (e.g. not directly subduction-related), age constraints and geochemical affinities of these rocks can help clarify the nature of that period of time between the end of closure of the proto-Atlantic ocean and the onset of transpressional deformation characteristic of much of the southern Appalachians. Available data suggest these two broad tectonic regimes are not easily separable.

The debate over details of the precise origin of Alleghanian granites will probably remain unresolved. The contradictory evidence, however, is best viewed as an indication of a changing tectonic regime. Clearly, the type and extent of subduction circa 300 Ma did not rival that seen in classical destructive margin settings. The most compelling argument for this is, in my own opinion, the lack of compositional diversity in the Alleghanian plutons. This is consistent with these melts being a low melt fraction of the crust, and inconsistent with the magmatic diversity which arises from the continual replenishment of source material within an active subduction zone. Some of the geochemical indicators of subduction present in the Alleghanian plutons could result from other, unrelated processes. For instance, negative Ta and Nb anomalies in the Danburg pluton may well result from fractionation of titanite as the mafic enclaves crystallized, or it may simply reflect the characteristics of the source area. The likely source rocks for these plutons are the Carolina terrane, which is itself believed to be a magmatic arc. Thus, melting of these rocks will likely yield melts with Ta-Nb depletions.

An interesting aspect of the data from the Danburg pluton is the composition of the parental magma of the mafic enclaves. Based on trace element abundances, this magma appears to have peralkaline or syenitic affinities. One argument against the prominence of subduction processes in generating the Alleghanian plutons is the lack of a gabbrosyenite component in the overall abundance of plutonic rocks. If assumptions made here about the composition of the enclave magma are true, then there was indeed magma with syenitic or peralkaline affinities being generated around 300 Ma. Exposures of the Delhi syenite on the western boundary of the Danburg pluton appear to contain quenched enclaves, although this has yet to be validated. The proximity of the Delhi syenite, coupled with these textures and the clear occurrence of magma mixing in the adjacent Danburg body, raises the possibility that the Delhi pluton is of Alleghanian age. Indeed, the magma that produced the Delhi syenite should be considered a candidate for the mafic enclave magma in the Danburg pluton. Therefore, future work should be directed toward resolving the ages of the syenitic bodies in this region. The long held assumption that many of these rocks are of Siluro-Devonian age should be challenged. In fact, the Siluro-Devonian Concord syenite "suite", as defined by others, is based on very few isotopic age determinations, yet the suite extends across the entire southernmost Appalachians. It may be that gabbro-to-syenite plutonism of Alleghanian age is more voluminous than is currently recognized.

Other than geochronological investigations, the study of mafic enclaves in other Alleghanian granites would be useful in this regard. Such enclaves remain unstudied in this portion of the orogen, although many of the granites contain them. For instance, in the immediate vicinity of the Danburg pluton, enclaves are present in the Appling, Siloam, and Sparta granites. These remain relatively or completely unknown in terms of their detailed chemistry, and are deserving of investigation. As many of the Alleghanian granites in the southern Appalachians were initially investigated prior to the renewed interest in mafic enclaves, magma mixing processes in these rocks have received little attention.

In theory, isotopic studies of these rocks should prove most useful, although this may prove to be of limited value. It has been clearly shown elsewhere that elemental exchange during enclave generation is very thorough, particularly in smaller enclaves. Data from this work suggests that isotopic ratios in enclaves have re-equilibrated with their host magmas quite readily. Future work should focus on finding large, meter-scale enclaves and resolving the isotopic signatures from the innermost portions of these enclaves. Insights into the earlier history of the Alleghanian granites can contribute to a better understanding of overall magma genesis during the Alleghanian orogeny.

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APPENDIX A: ANALYTICAL ACCURACY AND PRECISION

1		,200 00000 100	
analyses			
NBS 688	average stdev	published %	
		relativ	/e
SiO2	47.33 ± 0.01	48.35 2	
TiO2	1.15 ± 0.00	1.17 1	
A12O3	16.98 ± 0.08	17.35 2	
FeOt	10.14 ± 0.01	10.34 2	
MnO	0.16 ± 0.00	0.167 4	
MgO	8.44 ± 0.03	8.46 <1	
CaO	11.85 ± 0.01	12.17 3	
Na2O	2.24 ± 0.01	2.16 4	
K2O	0.18 ± 0.00	0.19 4	
P2O5	0.15 ± 0.00	0.133 9	
total	98.63 ±		
AGV-2	average stdev	published %	
		relativ	<i>v</i> e
V	124 ± 9	120 3	
Cr	21 ± 11	17 24	
Ni	23 ± 9	19 21	
Cu	52 ± 1	53 2	
Zn	90 ± 2	86 4	
Rb	68 ± 1	69 1	
Sr	676 ± 7	658 3	
Y	21 ± 1	20 5	
Zr	223 ± 4	230 3	
Nb	16 ± 3	15 7	
Ba	1087 ± 43	1140 5	
USGS G-2	average stdev	published %	
		relativ	/e
SiO2	69.19 ± 0.03	69.22 <1	
TiO2	0.49 ± 0.00	0.48 2	
Al2O3	15.33 ± 0.03	15.4 <1	
FeOt	2.59 ± 0.01	2.66 3	
MnO	0.03 ± 0.00	0.03 <1	
MgO	0.79 ± 0.02	0.75 5	
CaO	1.92 ± 0.02	1.96 2	
Na2O	4.17 ± 0.03	4.06 3	
K2O	4.42 ± 0.03	4.46 1	
P2O5	0.13 ± 0.00	0.14 8	
total	99.06		

APPENDIX A: Results of SRMs analyzed during XRF

analysis				-		
Kakanui hbl	average		stdev		published	% relative
SiO2	40.28	±	0.21		40.37	<1
A12O3	14.26	±	0.15		14.90	4
MgO	12.88	±	0.02		12.80	1
K2O	2.05	±	0.11		2.05	<1
FeO	10.74	±	0.29		10.92	2
TiO2	4.78	±	0.08		4.72	1
MnO	0.11	±	0.01		0.09	19
CaO	9.97	±	0.29		10.30	3
Cl	0.02	±	0.02			
F	0.36	±	0.09			
Na2O	2.50	±	0.09		2.60	4
Chuck Taylor						
Titanite	average		stdev		published	% relative
SiO2	30.69	±	0.62		30.83	<1
A12O3	1.18	±	0.09		1.36	13
FeO	0.56	±	0.08		1.31	58
MgO	0.00	±	0.00			
CaO	28.01	±	0.73		28.82	3
Na2O	0.01	±	0.01			
TiO2	36.79	±	0.34		37.80	3
MnO	0.04	±	0.03		0.05	25
F	0.21	±	0.04		0.08	156
Cr2O5	0.05	±	0.03			
ZrO2	0.02	±	0.02			
Nb2O5	0.27	±	0.28			
Ta2O5	0.04	±	0.08			
ORF7	single					
orthoclase	analysis		published	% relative		
SiO2	64.34		64.39	<1		
A12O3	18.81		18.58	1		
CaO	0.02					
Na2O	1.11		1.14	3		
K2O	15.36		14.92	3		
FeO	0.04		0.03	33		
TiO2	0					
MgO	0.02					
MnO	0.04					
SrO	0.05		0.04	25		
BaO	0.85		0.78	9		

APPENDIX A (cont.): Results of standards analyzed during microprobe analysis

APPENDIX A(cont.): Results of SRMs						
analyzed during INAA analyses						
BHVO-1	3HVO-1 determined publ. % relative					
La	16.6	17	2			
Sm	6.1	6.1	0			
Eu		2				
Hf						
Yb	2.07	1.9	9			
Lu	0.28	0.28	0			
Sc						
Co						
Та						

NBS 688	determined	publ.	% relative
La	5.25	5.3	1
Sm		2.3	18
Eu	0.95	1.1	14
Hf	1.4	1.6	13
Yb	2.14	2.1	2
Lu	0.33	0.34	3
Sc	35.24	38.1	8
Co	46.37	49.7	7
Та	0.32	0.31	2

BP-37	determined	publ.	% relative
La	126.9	123	3
Sm	18.9	17.3	9
Eu	4	3.96	1
Hf	9.2		
Yb	1.56	1.4	11
Lu	0.23	0.19	21
Sc	12.24	12	2
Со	33.29		
Та	1.66	1.6	4

APPENDIX B: XRF AND INAA WHOLE ROCK ANALYSES

APPENDIX B: Danburg (DG), Sandy Hill (SH), and enclave (E) WR analyses					
	DG2FG	DG302	DG201	DG106-2	DG303
	equigr.	equigr.	megacrystic	megacrystic	megacrystic
SiO2	62.97	64.34	66.99	70.05	70.95
TiO2	1.17	0.84	0.55	0.52	0.23
Al2O3	15.88	15.51	15.25	14.09	14.47
Fe2O3	5.69	4.08	3.22	2.71	1.35
MnO	0.12	0.76	0.05	0.05	0.02
MgO	2.84	1.74	0.83	0.71	0.44
CaO	4.07	2.74	2.32	2.06	2.05
Na2O	4.34	4.21	3.89	3.17	3.83
K2O	2.54	4.02	5.70	4.88	5.59
P2O5	0.39	0.24	0.16	0.13	0.08
<u>H2O+</u>	0.74	0.62	0.35	<u>0.66</u>	0.31
totals	100.75	99.10	99.31	99.03	99.32
V	57	49	34	28	1
Cr	52	26	15	21	21
Ni	21	18	15	10	17
Zn	191	131	128	125	133
Nb	41	10	26	22	9
Rb	134	178	176	166	155
Sr	313	295	411	402	405
Y	28	14	20	20	14
Zr	305	130	252	239	124
Ba	725	892	801	862	905
Hf	8	3	5	4	3
La	•	•	•	•	•
Ce	•	•	•	•	•
Sm	•	•	•	•	•
Eu	•	•	•	•	•
Yb	•	•	•	•	•
Lu	•	•	•	•	•
Hf	•	•	•	•	•
Та	•	•	•	•	•
Tb	•	•	•	•	•
Q	16.15	16.78	17.47	27.83	23.29
С				0.16	
OR	15.01	23.76	33.69	28.84	33.04
AB	36.73	35.63	32.92	26.82	32.41
AN	16.35	11.55	7.32	9.37	5.78
DI-DI	1.01	0.37	1.11		2.36
HY-EN	6.61	4.12	1.55	1.77	
MT		0.05			
IL	0.26	1.60	0.11	0.11	0.04
HM	5.69	4.05	3.22	2.71	1.35

APPENDIX B: Danburg (DG), Sandy Hill (SH), and enclave (E) WR analyses						
	DG106	89DG1	DG2X	DG310	SH40123	
	megacrystic	megacrystic	megacrystic	aplite	equigr.	
SiO2	70.96	71.80	72.52	74.86	71.27	
TiO2	0.52	0.42	0.80	0.17	0.43	
A12O3	14.51	14.29	12.23	12.63	14.61	
Fe2O3	2.67	2.09	3.65	1.37	2.30	
MnO	0.05	0.05	0.07	0.02	0.65	
MgO	0.80	0.92	1.50	0.29	0.55	
CaO	2.08	1.79	2.55	1.20	1.41	
Na2O	3.39	3.30	3.12	2.95	3.26	
K2O	4.89	5.25	2.93	5.29	4.82	
P2O5	0.13	0.09	0.25	0.03	0.11	
<u>H2O+</u>	0.34	0.38	<u>0.50</u>	0.33	<u>0.38</u>	
totals	100.34	100.38	100.12	99.14	99.79	
V	37	27	60	1	21	
Cr	18	19	96	20	20	
Ni	14	13	27	9	14	
Zn	124	159	98	180	177	
Nb	22	17	47	11	37	
Rb	161	182	160	155	725	
Sr	369	380	385	260	62	
Y	23	17	27	22	3	
Zr	235	143	520	126	101	
Ba	821	809	707	871	909	
Hf	5	5	12	4	3	
La	•	67	•	54	•	
Ce	•	113	•	84	•	
Sm	•	6.9	•	4.8	•	
Eu	•	1.3	•	0.84	•	
Yb	•	1.4	•	1.83	•	
Lu	•	0.21	•	0.28	•	
Hf	•	4.0	•	3.4	•	
Та	•	1.24	•	0.63	•	
Tb	•	0.69	•	0.54	•	
Q	27.24	27.56	36.16	34.53	30.33	
С	0.17	0.14			1.73	
OR	28.90	31.03	17.32	31.26	28.49	
AB	28.69	27.92	26.40	24.96	27.59	
AN	9.47	8.29	10.71	5.60	6.28	
DI-DI			0.24	0.12		
HY-EN	1.99	2.29	3.63	0.66	1.37	
MT					0.88	
IL	0.11	0.11	0.15	0.04	0.82	
HM	2.67	2.09	3.65	1.37	1.70	

APPENDIX B:	Danburg (DG	i), Sandy Hi	ll (SH), and e	nclave (E) W	R analyses
	SH501	SH412	SH410-2	SH413	SH411
	equigr.	equigr.	porphyritic	equigr.	equigr.
SiO2	71.60	72.20	73.63	73.75	74.06
TiO2	0.40	0.36	0.35	0.06	0.11
Al2O3	14.54	13.50	13.71	14.12	13.87
Fe2O3	2.16	2.15	2.02	0.57	0.84
MnO	0.03	0.06	0.06	0.02	0.05
MgO	0.52	0.50	0.38	0.13	0.17
CaO	1.37	1.30	1.38	0.46	0.61
Na2O	3.49	3.62	3.28	4.76	3.77
K2O	5.28	5.04	5.08	4.89	5.35
P2O5	0.10	0.08	0.08	0.06	0.01
<u>H2O+</u>	<u>0.26</u>	<u>0.53</u>	0.27	<u>0.31</u>	<u>0.44</u>
totals	99.75	99.34	100.24	99.13	99.28
V	33	11	9	1	13
Cr	16	17	19	41	18
Ni	10	16	13	21	18
Zn	186	136	135	138	141
Nb	11	26	21	55	27
Rb	298	659	475	513	600
Sr	225	63	74	76	77
Y	13	3	3	3	3
Zr	256	110	115	73	108
Ba	799	965	864	975	955
Hf	5	3	4	3	2
La	•	•	•	•	•
Ce	•	•	•	•	•
Sm	•	•	•	•	•
Eu	•	•	•	•	•
Yb	•	•	•	•	•
Lu	•	•	•	•	•
Hf	•	•	•	•	•
Та	•	•	•	•	•
Tb	•	•	•	•	•
Q	27.66	28.55	31.81	26.33	30.12
С	0.83		0.50	0.30	0.79
OR	31.20	29.79	30.02	28.90	31.62
AB	29.53	30.63	27.76	40.28	31.90
AN	6.14	5.70	6.32	1.89	2.96
DI-DI		0.18			
HY-EN	1.30	1.16	0.95	0.32	0.42
MT					
IL	0.06	0.13	0.13	0.04	0.11
HM	2.16	2.15	2.02	0.57	0.84
APPENDIX B:	Danburg (D	G), Sandy Hi	ll (SH), and e	nclave (E) WI	R analyses
-------------	-------------	--------------	----------------	---------------	-------------
	SH413-2	SH410	SH405-2	DG200LE	DG205E
	equigr.	porphyritic	equigr.	coalesced	coalesced
SiO2	74.97	75.43	77.27	64.25	58.95
TiO2	0.09	0.11	0.10	1.07	1.71
A12O3	14.01	13.13	13.31	15.28	14.78
Fe2O3	0.56	0.87	0.90	5.13	8.31
MnO	0.02	0.03	0.04	0.08	0.14
MgO	0.05	0.14	0.03	1.40	2.38
CaO	0.52	0.59	0.55	2.96	4.18
Na2O	4.56	3.82	3.27	3.53	3.66
K2O	4.91	4.89	5.25	5.50	4.18
P2O5	0.07	0.02	0.01	0.30	0.62
<u>H2O+</u>	<u>0.14</u>	<u>0.37</u>	<u>0.21</u>	<u>0.77</u>	<u>0.79</u>
totals	99.90	99.40	100.94	100.27	99.70
V	10	24	11	72	119
Cr	18	20	17	15	9
Ni	9	15	8	8	9
Zn	140	133	175	193	194
Nb	23	29	16	57	68
Rb	490	268	430	150	170
Sr	79	235	55	445	298
Y	3	17	7	29	27
Zr	60	203	193	415	407
Ba	971	869	950	611	487
Hf	3	4	3	10	11
La	•	88	•	•	177
Ce	•	142	•	•	406
Sm	•	7.1	•	•	11.9
Eu	•	1.1	•	•	2.38
Yb	•	2.26	•	•	2.77
Lu	•	0.48	•	•	0.50
Hf	•	6.1	•	•	14.3
Та	•	2.14	•	•	1.70
Tb	•	0.73	•	٠	1.20
Q	28.66	33.08	36.96	15.08	10.90
С	0.42	0.53	1.27		
OR	29.02	28.90	31.03	32.50	24.70
AB	38.59	32.33	27.67	29.87	30.97
AN	2.12	2.80	2.66	9.60	1.56
DI-DI				2.43	4.00
HY-EN	0.12	0.35	0.07	2.36	4.08
MT					
IL	0.04	0.06	0.09	0.17	0.30
HM	0.56	0.87	0.90	5.13	8.31

APPENDIX B:	Danburg (D	G), Sandy Hil	l (SH), and er	nclave (E) WR	analyses
	DG304E	DG305E	DG308E	E-U-6	DG105E
	coalesced	coalesced	coalesced	coalesced	microgr.
SiO2	59.93	59.86	61.96	63.23	63.02
TiO2	1.38	1.36	1.05	1.07	1.13
Al2O3	15.69	15.34	15.93	15.88	15.62
Fe2O3	6.95	7.01	5.35	5.34	5.95
MnO	0.12	0.14	0.10	0.10	0.12
MgO	1.89	3.27	2.01	2.06	2.74
CaO	3.22	4.33	4.08	3.86	4.09
Na2O	3.37	4.18	4.19	4.17	4.26
K2O	6.03	2.31	3.37	3.17	2.73
P2O5	0.47	0.52	0.31	0.32	0.38
<u>H2O+</u>	<u>0.65</u>	0.44	<u>0.30</u>	<u>0.77</u>	0.32
totals	99.70	98.76	98.65	99.97	100.36
V	62	128	101	102	114
Cr	10	67	28	34	60
Ni	11	36	15	19	33
Zn	188	191	190	191	192
Nb	68	41	41	47	32
Rb	187	157	129	142	154
Sr	409	290	392	377	322
Y	32	29	25	29	22
Zr	490	270	356	360	325
Ba	700	580	653	648	616
Hf	10	8	9	9	9
La	138	104	•	•	115
Ce	354	270	•	•	286
Sm	15.5	12.0	•	•	11.5
Eu	2.25	2.22	•	•	1.54
Yb	3.34	2.68	•	•	1.62
Lu	0.49	0.40	•	•	0.33
Hf	15.6	•	•	•	10.1
Та	2.70	1.60	•	•	0.90
Tb	1.52	1.24	•	•	1.02
Q	8.85	14.01	14.58	16.40	16.01
С					
OR	35.64	13.65	19.92	18.73	16.13
AB	28.52	33.37	35.46	35.29	36.05
AN	9.88	16.27	14.71	15.25	15.40
DI-DI	2.36	1.41	0.19	1.41	1.85
HY-EN	3.61	7.49	4.92	4.48	5.97
MT					
IL	0.26	0.30	0.21	0.21	0.26
HM	6.95	7.01	5.35	5.34	5.95

APPENDIX B:	Danburg (DO	G), Sandy Hill	(SH), and en	clave (E) WR	analyses
	DG204E	E-U-1	E-U-3	E-U-4	DG206E
	microgr.	microgr.	microgr.	microgr.	ocelli
SiO2	60.67	58.22	58.98	60.56	58.71
TiO2	1.26	1.84	1.31	1.19	1.78
Al2O3	15.51	15.98	17.08	16.68	15.36
Fe2O3	6.31	8.57	6.26	6.30	7.26
MnO	0.14	0.14	0.11	0.12	0.13
MgO	2.57	2.41	1.64	1.82	2.22
CaO	4.73	4.67	2.60	3.02	4.01
Na2O	4.27	4.72	3.22	3.85	3.17
K2O	3.19	2.37	7.93	5.72	4.03
P2O5	0.42	0.61	0.38	0.39	0.65
<u>H2O+</u>	<u>0.69</u>	<u>0.48</u>	<u>0.37</u>	<u>0.35</u>	<u>0.83</u>
totals	99.76	100.01	99.88	100.00	98.15
V	95	140	83	97	115
Cr	11	19	5	14	54
Ni	5	11	2	8	12
Zn	195	199		115	202
Nb	75	185		91	72
Rb	217	140		240	145
Sr	333	255		341	287
Y	25	68		31	31
Zr	491	557		574	402
Ba	565	426		563	431
Hf	12	16		13	13
La	167	•	•	151	•
Ce	399	•	•	333	•
Sm	11.0	•	•	24.4	•
Eu	2.00	•	•	3.00	•
Yb	3.07	•	•	4.53	•
Lu	0.49	•	•	0.71	•
Hf	13.7	•	•	19.0	•
Та	1.71	•	•	4.31	•
Tb	1.03	•	•	2.22	•
Q	12.35	9.81	2.95	8.19	14.77
С					0.05
OR	18.85	14.01	46.86	33.80	23.82
AB	36.13	39.94	27.25	32.58	26.82
AN	13.73	15.42	8.73	1.34	15.65
DI-DI	2.45	2.93	1.31	0.85	
HY-EN	5.26	4.64	3.48	4.14	5.53
MT					
IL	0.30	0.30	0.24	0.26	0.28
HM	6.31	8.57	6.26	6.30	7.26

APPENDIX B:	Danburg (DC	G), Sandy Hill	(SH), and end	clave (E) WR a	analyses
	DG207E	DG307E	DG309E	E-U-2	E-U-7
	ocelli	ocelli	ocelli	ocelli	ocelli
SiO2	66.10	58.89	58.24	58.42	56.71
TiO2	0.79	1.58	1.41	1.85	1.47
Al2O3	15.04	15.99	16.62	16.05	17.05
Fe2O3	4.07	7.17	6.93	7.70	7.51
MnO	0.06	0.14	0.11	0.14	0.14
MgO	1.05	2.41	1.87	2.41	2.92
CaO	2.17	4.92	3.79	4.71	4.69
Na2O	3.29	4.62	3.52	4.68	5.00
K2O	6.26	2.60	6.22	2.39	2.37
P2O5	0.18	0.49	0.40	0.61	0.45
<u>H2O+</u>	<u>0.42</u>	<u>0.40</u>	<u>0.51</u>	<u>0.44</u>	<u>0.44</u>
totals	99.43	99.20	99.62	99.40	98.75
V	126	129	99	124	150
Cr	32	33	8	61	30
Ni	24	16	4	31	15
Zn	195	192	196	193	191
Nb	42	50	87	37	57
Rb	126	156	137	153	159
Sr	365	328	586	296	331
Y	27	23	34	25	25
Zr	341	430	603	363	461
Ba	608	564	515	607	535
Hf	8	12	13	11	12
La	116	148	175	•	•
Ce	191	361	432	•	•
Sm	11.5	10.6	20.1	•	•
Eu	1.75	1.80	4.00	•	•
Yb	2.18	2.11	3.83	•	•
Lu	0.40	0.43	0.64	•	•
Hf	9.0	11.7	17.7	•	•
Та	1.09	0.93	1.60	•	•
Tb	1.14	0.83	1.91	•	•
Q	17.29	10.60	5.26	10.08	5.42
С					
OR	37.00	15.37	36.76	14.12	14.01
AB	27.84	39.09	29.79	39.60	42.31
AN	7.78	15.21	11.18	15.73	17.08
DI-DI	1.41	0.81	0.42	2.85	2.53
HY-EN	1.96	5.63	4.47	4.68	6.10
MT					
IL	0.13	0.30	0.24	0.30	0.30
HM	4.07	7.17	6.93	7.70	7.51

APPENDIX B: Danburg (DG), Sandy Hill (SH), and enclave (E) WR analyses							
	E-U-8	DG202sch	E-U-5				
	ocelli	micaceous	micaceous				
SiO2	59.57	57.81	49.59				
TiO2	1.31	2.03	2.38				
A12O3	15.93	13.98	16.04				
Fe2O3	6.64	10.68	12.77				
MnO	0.13	0.17	0.25				
MgO	2.41	3.35	5.36				
CaO	5.12	4.05	4.69				
Na2O	4.55	3.42	3.89				
K2O	2.81	3.90	3.79				
P2O5	0.37	0.61	0.70				
<u>H2O+</u>	0.32	<u>0.35</u>	<u>1.01</u>				
totals	99.16	100.35	100.47				
V	105	134	210				
Cr	28	40	100				
Ni	12	13	36				
Zn	196	106	121				
Nb	42	151	53				
Rb	116	177	258				
Sr	367	267	211				
Y	31	54	19				
Zr	341	666	285				
Ba	583	365	210				
Hf	9	18	8				
La	•	255	•				
Ce	•	475	•				
Sm	•	31.5	•				
Eu	•	3.80	•				
Yb	•	6.02	•				
Lu	•	0.94	•				
Hf	•	25.9	•				
Та	•	5.16	•				
Tb	•	2.89	•				
Q	10.60	11.03					
С							
OR	16.61	23.05	22.40				
AB	38.50	28.94	32.92				
AN	14.74	11.28	15.11				
DI-DI	3.26	3.76	2.79				
HY-EN	4.49	6.60					
MT							
IL	0.28	0.36	0.53				
HM	6.64	10.68	12.77				

APPENDIX C: PLAGIOCLASE MICROPROBE ANALYSES

Sample	DG D1	DG D1	DG D1	DG D1	DG D1	DG D1	DG D1
	core	core	core	core	core	core	core
8:00	(0.71	(2.17	(1.5)	(2.22	55.04	(1.02	(1.24
S102	62./1	63.17	61.56	63.32	55.94	61.02	61.34
1102	0.03	0.01	0.01	0.02	0.49	0.04	0.00
AI2O3	23.88	23.63	24.13	23.33	26.64	24.42	24.34
FeO	0.30	0.15	0.28	0.16	2.18	0.21	0.16
MnO	•	•	•	•	•	•	•
MgO	0.01	0.01	0.01	0.00	0.00	0.00	0.00
CaO	5.10	4.31	5.23	4.26	8.17	5.80	5.40
BaO	0.00	0.00	0.07	0.06	0.00	0.00	0.03
SrO	•	•	•	•	•	•	•
Na2O	8.46	9.20	8.35	8.90	6.41	8.08	8.28
K2O	0.40	0.09	0.33	0.64	0.20	0.25	0.40
CalcTotal	100.89	100.57	99.97	100.69	100.03	99.82	99.95
formula calcul	ations		8 O basis				
Si	2.758	2.779	2.736	2.788	2.534	2.717	2.727
Al	1.238	1.225	1.264	1.211	1.422	1.282	1.276
Fe2	0.011	0.006	0.010	0.006	0.083	0.008	0.006
Mg	0.001	0.001	0.001	0.000	0.000	0.000	0.000
Ca	0.240	0.203	0.249	0.201	0.396	0.277	0.257
Na	0.722	0.785	0.720	0.760	0.563	0.698	0.714
Κ	0.022	0.005	0.019	0.036	0.012	0.014	0.023
Ti	0.001	0.000	0.000	0.001	0.017	0.001	0.000
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sr	•	•	•	•	•	•	•
Ba	0.000	0.000	0.001	0.001	0.000	0.000	0.001
Total Cat	4.994	5.003	5.000	5.004	5.026	4.997	5.003
mol %							
Albite	73	79	73	76	58	71	72
Anorthite	24	20	25	20	41	28	26
Orthoclase	2	1	2	4	1	1	2

APPENDIX C: plag. analyses; Danburg (DG), Sandy Hill (SH), & mafic enclaves (E)

Sample	DG D1	DG 301	DG 301	DG 301	DG 301	DG 306	DG 306
	core	core	core	core	core	core	core
SiO2	61 70	60.68	60.51	63.03	61.26	62.22	60.85
5102	01.79	0.00	00.51	03.95	01.20	02.22	00.05
1102	0.01	24.22	24.25	22 22	24.22	24.48	24.52
AI2O5	24.57	24.52	24.23	25.55	24.52	24.40	24.33
MnO	0.10	0.52	0.23	0.12	0.15	0.52	0.18
MaO	0.02	0.00	0.00	0.00	0.00	0.01	0.00
CaO	5.50	5.76	5.87	1 34	5.66	5 30	5 55
CaO RoO	0.12	0.08	0.03	4.54	0.00	0.00	0.00
BaO SrO	0.12	0.08	0.05	0.00	0.09	0.00	0.00
$N_{2}O$	8 /3	8 02	7 80	8 56	8 66	7 83	7 01
K20	0.43	0.02	0.58	0.50	0.15	0.67	0.32
CalcTotal	100.66	99.48	99.31	100.80	100.30	100.94	99.40
formula calcu	lations		8 O basis				
Si	2.729	2.715	2.714	2.802	2.719	2.738	2.718
Al	1.269	1.283	1.282	1.205	1.272	1.269	1.291
Fe2	0.007	0.012	0.009	0.004	0.005	0.012	0.007
Mg	0.001	0.000	0.000	0.000	0.000	0.001	0.000
Ca	0.260	0.276	0.282	0.204	0.269	0.254	0.266
Na	0.722	0.696	0.678	0.728	0.745	0.668	0.685
Κ	0.014	0.017	0.033	0.029	0.008	0.038	0.018
Ti	0.000	0.000	0.001	0.000	0.001	0.001	0.002
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sr	•	•	•	•			
Ba	0.002	0.001	0.001	0.000	0.002	0.000	0.000
Total Cat	5.004	5.000	5.000	4.973	5.021	4.980	4.986
mol %							
Albite	73	70	68	76	73	70	71
Anorthite	26	28	28	21	26	26	27
Orthoclase	1	2	3	3	1	4	2

APPENDIX C: plag. analyses; Danburg (DG), Sandy Hill (SH), & mafic enclaves (E)

Sample	DG 306	DG D1	DG D1	DG D1	DG D1	DG D1	DG D1
-	core	interm.	interm.	interm.	interm.	interm.	interm.
SiO2	61.89	62.28	61.35	58.85	58.89	60.82	61.98
TiO2	0.02	0.04	0.04	0.03	0.00	0.00	0.00
Al2O3	23.81	24.03	24.78	26.71	26.17	24.96	24.78
FeO	0.24	0.13	0.13	0.06	0.22	0.22	0.23
MnO	•	•	•	•	•	•	•
MgO	0.01	0.01	0.01	0.00	0.00	0.00	0.00
CaO	5.21	5.32	5.98	8.30	7.83	6.28	6.14
BaO	0.03	0.02	0.04	0.08	0.03	0.00	0.03
SrO	•	•	•	•	•	•	•
Na2O	8.24	8.22	8.13	6.63	6.94	7.90	7.71
K2O	0.50	0.19	0.14	0.26	0.27	0.39	0.17
CalcTotal	99.95	100.24	100.60	100.92	100.35	100.57	101.04
formula calcu	lations		8 O basis				
Si	2.750	2.752	2.710	2.608	2.624	2.694	2.722
Al	1.247	1.252	1.290	1.395	1.374	1.303	1.283
Fe2	0.009	0.005	0.005	0.002	0.008	0.008	0.008
Mg	0.001	0.001	0.001	0.000	0.000	0.000	0.000
Ca	0.248	0.252	0.283	0.394	0.374	0.298	0.289
Na	0.710	0.704	0.696	0.570	0.600	0.679	0.657
Κ	0.028	0.011	0.008	0.015	0.015	0.022	0.010
Ti	0.001	0.001	0.001	0.001	0.000	0.000	0.000
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sr							
Ba	0.001	0.000	0.001	0.001	0.001	0.000	0.001
Total Cat	4.995	4.978	4.995	4.986	4.996	5.004	4.969
mol %							
Albite	72	73	71	58	61	68	69
Anorthite	25	26	29	40	38	30	30
Orthoclase	3	1	1	2	2	2	1

APPENDIX C: plag. analyses; Danburg (DG), Sandy Hill (SH), & mafic enclaves (E)

APPE	NDIX	C: pl	lag. ana	alyses; I	Danburg
(\mathbf{DC})	Candra	TT:11	(CII)	0	

(DG), Sandy H	lill (SH), &	mafic enc	laves (E)				
Sample	DG D1	DG D1	DG D1	DG 301	DG 301	DG 301	DG 301
	interm.	interm.	interm.	interm.	interm.	interm.	interm.
SiO2	59.86	61.50	60.36	61.39	60.44	61.08	62.51
TiO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al2O3	25.14	23.60	24.82	23.73	24.26	24.12	23.19
FeO	0.12	0.17	0.17	0.09	0.24	0.32	0.11
MnO	•	•	•	•	•	•	•
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	6.53	5.24	6.32	5.30	5.69	5.48	4.17
BaO	0.06	0.06	0.07	0.04	0.07	0.01	0.00
SrO	•	•	•	•	•	•	•
Na2O	7.46	8.05	7.68	8.31	8.10	8.07	9.32
K2O	0.10	0.44	0.32	0.17	0.41	0.49	0.14
CalcTotal	99.27	99.06	99.74	99.03	99.21	99.57	99.44
formula			8 O hasis				<u> </u>
calculations			0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0				
Si	2.682	2.755	2.695	2.749	2.713	2.729	2.783
Al	1.327	1.246	1.306	1.252	1.284	1.270	1.217
Fe2	0.004	0.006	0.006	0.003	0.009	0.012	0.004
Mg	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ca	0.313	0.251	0.302	0.254	0.274	0.262	0.199
Na	0.648	0.699	0.665	0.721	0.705	0.699	0.804
К	0.006	0.025	0.018	0.010	0.023	0.028	0.008
Ti	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sr							
Ba	0.001	0.001	0.001	0.001	0.001	0.000	0.000
Total Cat	4.982	4.984	4.994	4.991	5.009	5.000	5.015
mol %							
Albite	67	72	67	73	70	71	80
Anorthite	32	26	31	26	27	27	20
Orthoclase	1	3	2	1	2	3	1

(DG), Sandy H	Hill (SH), &	t mafic enc	laves (E)				
Sample	DG 306	DG 306	DG D1	DG D1	DG D1	DG D1	DG D1
-	interm.	interm.	rim	rim	rim	rim	rim
SiO2	61.47	61.90	63.17	68.17	68.03	64.77	61.35
TiO2	0.00	0.00	0.00	0.00	0.00	0.02	0.00
A12O3	23.49	23.71	23.64	20.18	19.94	22.25	25.22
FeO	0.13	0.33	0.09	0.03	0.02	0.09	0.04
MnO	•	•	•	•	•	•	•
MgO	0.00	0.00	0.01	0.00	0.01	0.00	0.02
CaO	4.96	5.15	4.10	0.48	0.26	3.05	6.31
BaO	0.00	0.01	0.00	0.00	0.06	0.00	0.05
SrO	•	•	•	•	•	•	•
Na2O	8.75	8.23	9.27	11.60	11.84	9.76	7.78
K2O	0.21	0.49	0.10	0.10	0.18	0.09	0.08
CalcTotal	99.01	99.82	100.38	100.56	100.34	100.03	100.85
formula		1	8 O basis				
calculations							
Si	2.755	2.754	2.782	2.966	2.970	2.851	2.701
Al	1.241	1.243	1.227	1.035	1.026	1.154	1.309
Fe2	0.005	0.012	0.003	0.001	0.001	0.003	0.001
Mg	0.000	0.000	0.001	0.000	0.001	0.000	0.001
Ca	0.238	0.246	0.193	0.022	0.012	0.144	0.298
Na	0.760	0.710	0.791	0.979	1.002	0.833	0.664
Κ	0.012	0.028	0.006	0.006	0.010	0.005	0.004
Ti	0.000	0.000	0.000	0.000	0.000	0.001	0.000
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sr							
Ba	0.000	0.000	0.000	0.000	0.001	0.000	0.001
Total Cat	5.011	4.993	5.003	5.009	5.023	4.991	4.979
mol %							
Albite	75	72	80	97	98	85	69
Anorthite	24	25	20	2	1	15	31
Orthoclase	1	3	1	1	1	1	0

APPENDIX C: plag. analyses; Danburg	2
(\mathbf{DC}) Condu IIII (CII) \mathbf{e} motio analog	

Sample	DG D1	DG D1	DG D1	DG 301	DG 301	DG 306	DG 306
-	rim	rim	rim	rim	rim	rim	rim
SiO2	61.83	62.80	62.01	67.81	62 75	61 75	62.45
$T_{i}O^2$	01.85	02.89	02.91	07.01	02.75	01.75	02.43
A12O3	23.87	23.40	23 32	10.05	22.86	2/ 30	23.05
FeO	0.06	0.17	0.10	0.06	0.17	0.18	23.03
MnO	•	•	•	0.00	•	•	•
MσO	0.00	0.02	0.00	0.00	0.00	0.00	0.03
CaO	5.13	4 54	4 44	0.00	3 97	5.61	4 21
BaO	0.06	0.08	0.00	0.01	0.01	0.00	0.00
SrO	•	•	•	•	•	•	•
Na2O	8.78	9.10	8.75	10.58	8.63	8.18	8.63
K2O	0.11	0.27	0.33	0.08	0.68	0.11	0.24
CalcTotal	99.84	100.48	99.85	99.14	99.07	100.22	98.71
formula			8 O basis				
calculations							
Si	2.748	2.776	2.787	2.983	2.803	2.733	2.794
Al	1.250	1.217	1.218	1.026	1.203	1.272	1.215
Fe2	0.002	0.006	0.004	0.002	0.006	0.007	0.003
Mg	0.000	0.001	0.000	0.000	0.000	0.000	0.002
Ca	0.244	0.215	0.211	0.037	0.190	0.266	0.202
Na	0.757	0.779	0.752	0.902	0.747	0.702	0.749
K	0.006	0.015	0.019	0.004	0.039	0.006	0.014
Ti	0.000	0.000	0.000	0.001	0.000	0.000	0.001
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sr							
Ba	0.001	0.001	0.000	0.000	0.000	0.000	0.000
Total Cat	5.008	5.012	4.989	4.956	4.989	4.985	4.979
mol %							
Albite	75	77	77	96	77	72	78
Anorthite	24	21	21	4	19	27	21
Orthoclase	1	2	2	0	4	1	1

Sample	DG 306	DG 302	DG 302	320 sch.	320 sch.	320 sch.	320 sch.
Ĩ	rim	aplite	aplite	intercum.	intercum.	intercum.	intercum.
SiO2	63.35	61.23	61.61	60.21	61.13	59.33	60.29
TiO2	0.01	0.00	0.00	0.02	0.00	0.02	0.00
Al2O3	22.98	23.60	23.49	24.03	23.88	24.05	23.72
FeO	0.11	0.07	0.00	0.16	0.23	0.18	0.17
MnO	•	0.06	0.00	0.00	0.00	0.02	0.02
MgO	0.00	0.01	0.00	0.00	0.00	0.00	0.00
CaO	4.31	4.85	4.52	5.40	5.46	5.57	5.34
BaO	0.02	0.00	0.00	0.05	0.00	0.00	0.05
SrO	•	•	•	•	•	•	•
Na2O	8.73	8.57	9.36	8.42	8.20	8.31	8.34
K2O	0.30	0.14	0.09	0.20	0.23	0.15	0.16
CalcTotal	99.81	98.53	99.07	98.49	99.13	97.63	98.09
formula			8 O basis				
calculations							
Si	2.804	2.753	2.758	2.719	2.738	2.705	2.731
Al	1.199	1.251	1.239	1.279	1.261	1.292	1.266
Fe2	0.004	0.003	0.000	0.006	0.009	0.007	0.006
Mg	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Ca	0.204	0.234	0.217	0.261	0.262	0.272	0.259
Na	0.749	0.747	0.812	0.737	0.712	0.734	0.733
K	0.017	0.008	0.005	0.012	0.013	0.009	0.009
Ti	0.000	0.000	0.000	0.001	0.000	0.001	0.000
Mn	0.000	0.002	0.000	0.000	0.000	0.001	0.001
Sr							
Ba	0.000	0.000	0.000	0.001	0.000	0.000	0.001
Total Cat	4.979	4.999	5.031	5.015	4.994	5.020	5.007
mol %							
Albite	77	76	79	73	72	72	73
Anorthite	21	24	21	26	27	27	26
Orthoclase	2	1	0	1	1	1	1

APPENDIX C: plag. analyses; Danburg (DG), Sandy Hill (SH), & mafic enclaves (E)

APPENDIX C: plag analyses: Danburg	T
ATTENDIA C. plag. analyses, Danouig	5
(DC) Candy IIII (CII) & matia analow	

(DG), Sandy	Hill (SH), &	k mafic enc	claves (E)				
Sample	320 sch.	320 sch.	SH 410	SH 410	SH 410	SH 410	SH 410
	intercum.	intercum.	core	core	core	core	interm.
SiO2	60.15	59.99	63.68	62.07	64.98	60.63	62.33
TiO2	0.00	0.06	0.00	0.04	0.01	0.03	0.00
Al2O3	24.49	23.97	22.34	23.70	21.69	24.62	24.36
FeO	0.12	0.23	0.23	0.10	0.12	0.02	0.17
MnO	0.04	0.05	•	•	•	•	•
MgO	0.00	0.00	0.00	0.00	0.01	0.00	0.00
CaO	6.08	5.39	3.75	5.13	2.66	5.68	5.44
BaO	0.00	0.04	0.04	0.00	0.00	0.05	0.04
SrO	•	•	•	•	•	•	•
Na2O	8.15	8.07	9.20	8.48	10.02	8.35	8.30
K2O	0.28	0.26	0.28	0.23	0.22	0.13	0.26
CalcTotal	99.31	98.06	99.52	99.75	99.71	99.51	100.90
formula			8 O basis				
calculations							
Si	2.698	2.720	2.827	2.758	2.870	2.708	2.741
Al	1.295	1.281	1.169	1.241	1.129	1.296	1.263
Fe2	0.005	0.009	0.009	0.004	0.004	0.001	0.006
Mg	0.000	0.000	0.000	0.000	0.001	0.000	0.000
Ca	0.292	0.262	0.178	0.244	0.126	0.272	0.256
Na	0.709	0.709	0.792	0.731	0.858	0.723	0.708
K	0.016	0.015	0.016	0.013	0.012	0.007	0.015
Ti	0.000	0.002	0.000	0.001	0.000	0.001	0.000
Mn	0.002	0.002	•	•	•	•	•
Sr			•	•	•	•	•
Ba	0.000	0.001	0.001	0.000	0.000	0.001	0.001
Total Cat	5.017	5.000	4.992	4.992	5.001	5.009	4.989
mol %							
Albite	70	72	80	74	86	72	72
Anorthite	29	27	18	25	13	27	26
Orthoclase	2	2	2	1	1	1	1

APPENDIX C: plag. analyses; Danburg	5
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(DG), Sandy H	<u>ill (SH),</u> &	mafic enc	laves (E)				
Sample	SH 410	SH 410	SH 410	SH 410	SH 410	SH 410	enclave
	interm.	rim	rim	rim	rim	rim	ophitic
SiO2	65.21	65.39	64.04	69.50	66.10	65.40	64.20
TiO2	0.02	0.00	0.02	0.01	0.00	0.08	0.00
A12O3	21.75	22.24	22.58	20.57	21.07	21.95	22.42
FeO	0.05	0.13	0.16	0.04	0.04	0.08	0.00
MnO	•	•	•	•	•	•	0.00
MgO	0.00	0.00	0.02	0.00	0.01	0.01	0.00
CaO	2.38	2.93	3.28	0.11	1.99	2.54	3.43
BaO	0.06	0.00	0.00	0.01	0.00	0.08	0.03
SrO	•	•	•	•	•	•	0.22
Na2O	10.36	8.68	9.49	9.13	10.37	9.88	9.69
K2O	0.15	0.39	0.27	0.09	0.12	0.13	0.09
CalcTotal	99.98	99.76	99.86	99.46	99.70	100.15	100.08
formula			8 O basis				
calculations							
Si	2.872	2.874	2.829	3.014	2.909	2.871	2.833
Al	1.129	1.152	1.176	1.052	1.093	1.136	1.166
Fe2	0.002	0.005	0.006	0.001	0.001	0.003	0.000
Mg	0.000	0.000	0.001	0.000	0.001	0.001	0.000
Ca	0.112	0.138	0.155	0.005	0.094	0.119	0.162
Na	0.885	0.740	0.813	0.768	0.885	0.841	0.829
Κ	0.008	0.022	0.015	0.005	0.007	0.007	0.005
Ti	0.001	0.000	0.001	0.000	0.000	0.003	0.000
Mn	•	•	•	•	•	•	0.000
Sr	•	•	•	•	•	•	0.006
Ba	0.001	0.000	0.000	0.000	0.000	0.001	0.001
Total Cat	5.01	4.931	4.996	4.846	4.99	4.982	5.001
mol %							
Albite	88	82	83	99	90	87	83
Anorthite	11	15	16	1	10	12	16
Orthoclase	1	2	2	1	1	1	1

(DG), Sandy F	1111 (SH), &	manc enc	aves (E)				
Sample	enclave	enclave	enclave	enclave	enclave	enclave	enclave
	ophitic	ophitic	ophitic	ophitic	ophitic	ophitic	ophitic
				core	core	rim	inclusion
SiO2	62.12	63.21	62.12	61.79	61.14	62.02	61.64
TiO2	0.03	0.00	0.05	0.03	0.07	0.04	0.02
Al2O3	24.14	24.44	23.84	24.53	24.54	23.81	24.20
FeO	0.12	0.05	0.17	0.06	0.11	0.11	0.09
MnO	0.05	0.00	0.00	0.04	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.02	0.00	0.00	0.00
CaO	5.39	4.95	5.20	5.64	5.77	4.88	5.25
BaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SrO	0.17	0.19	0.23	0.18	0.19	0.17	0.22
Na2O	8.78	8.71	8.39	8.02	8.34	8.67	8.78
K2O	0.12	0.07	0.14	0.14	0.17	0.14	0.06
CalcTotal	100.92	101.62	100.14	100.45	100.33	99.84	100.26
formula			8 O basis				
calculations							
Si	2.737	2.755	2.753	2.729	2.712	2.755	2.732
Al	1.254	1.255	1.245	1.277	1.283	1.246	1.264
Fe2	0.004	0.002	0.006	0.002	0.004	0.004	0.003
Mg	0.000	0.000	0.000	0.001	0.000	0.000	0.000
Ca	0.254	0.231	0.247	0.267	0.274	0.232	0.249
Na	0.750	0.736	0.721	0.687	0.717	0.747	0.755
Κ	0.007	0.004	0.008	0.008	0.010	0.008	0.003
Ti	0.001	0.000	0.002	0.001	0.002	0.001	0.001
Mn	0.002	0.000	0.000	0.001	0.000	0.000	0.000
Sr	0.004	0.005	0.006	0.005	0.005	0.004	0.006
Ba	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total Cat	5.014	4.988	4.987	4.979	5.008	4.998	5.014
mol %							
Albite	74	76	74	71	72	76	75
Anorthite	25	24	25	28	27	24	25
Orthoclase	1	0	1	1	1	1	0

APPENDIX C: plag. analyses; Danburg (DG) Sandy Hill (SH) & mafic enclayes (E)

(DG), Sandy E	iiii (SH), &	mane enc	laves (E)				
Sample	enclave	enclave	enclave	enclave	enclave	enclave	enclave
	ophitic	ophitic	ophitic	ophitic	ophitic	ophitic	ophitic
		core					
SiO2	65.32	60.86	65.73	61.48	62.38	96.50	62.91
TiO2	0.03	0.00	0.00	0.00	0.02	0.00	0.00
Al2O3	21.59	24.17	21.29	24.05	23.94	0.03	23.10
FeO	0.02	0.15	0.04	0.23	0.19	0.00	0.14
MnO	0.03	0.00	0.03	0.03	0.01	0.02	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	2.35	5.72	1.91	5.44	5.05	0.01	4.35
BaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SrO	0.21	0.19	0.19	0.19	0.23	0.25	0.21
Na2O	10.32	8.40	10.65	8.45	8.76	0.00	8.79
K2O	0.05	0.18	0.07	0.20	0.18	0.00	0.27
CalcTotal	99.92	99.67	99.91	100.07	100.76	96.81	99.77
formula			8 O hasis				
calculations			0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0				
Si	2 878	2 7 1 9	2 894	2 733	2 751	3 995	2 792
A1	1 121	1 273	1 105	1 260	1.751	0.001	1 208
Fe2	0.001	0.006	0.001	0.009	0.007	0.001	0.005
Λc2 Mg	0.000	0.000	0.001	0.000	0.007	0.000	0.000
Ca	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Na	0.882	0.274	0.000	0.237	0.239	0.000	0.207
K	0.002	0.720	0.004	0.720	0.742	0.000	0.015
Ti	0.005	0.010	0.004	0.000	0.010	0.000	0.010
Mn	0.001	0.000	0.000	0.000	0.001	0.000	0.000
Sr	0.001	0.000	0.001	0.001	0.000	0.001	0.000
Ba	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Da	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total Cat	5.003	5.014	5.010	5.007	5.006	4.004	4.990
mol %							
Albite	89	72	91	73	75	0	77
Anorthite	11	27	9	26	24	100	21
Orthoclase	0	1	0	1	1	0	2

APPENDIX C: plag. analyses; Danburg (DG) Sandy Hill (SH), & mafic enclayes (E)

(DG), Sandy H	Hill (SH), &	mafic end	claves (E)				
Sample	enclave	enclave	enclave	enclave	enclave	enclave	enclave
	matrix	matrix	matrix	matrix	matrix	matrix	matrix
	rim	interm.	sieved c.				
SiO2	63.56	62.27	66.48	55.81	61.05	62.84	61.42
TiO2	0.03	0.04	0.00	0.04	0.01	0.00	0.00
A12O3	22.95	23.60	21.18	28.04	24.37	23.40	24.54
FeO	0.04	0.09	0.04	0.13	0.13	0.11	0.20
MnO	0.00	0.01	0.02	0.06	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.04
CaO	3.99	4.67	10.80	9.77	5.51	4.48	5.75
BaO	0.00	0.00	0.89	0.00	0.00	0.00	0.00
SrO	0.18	0.20	0.83	0.24	0.22	0.22	0.25
Na2O	9.78	8.77	0.79	5.98	8.45	9.12	8.19
K2O	0.08	0.07	0.38	0.17	0.18	0.27	0.24
CalcTotal	100.61	99.72	101.41	100.24	99.92	100.44	100.63
formula			8 O basis				
calculations							
Si	2.799	2.766	2.893	2.509	2.719	2.776	2.717
Al	1.191	1.236	1.086	1.486	1.279	1.218	1.279
Fe2	0.001	0.003	0.001	0.005	0.005	0.004	0.007
Mg	0.000	0.000	0.000	0.000	0.000	0.000	0.003
Ca	0.188	0.222	0.503	0.471	0.263	0.212	0.273
Na	0.835	0.755	0.067	0.521	0.730	0.781	0.702
Κ	0.004	0.004	0.021	0.010	0.010	0.015	0.014
Ti	0.001	0.001	0.000	0.001	0.000	0.000	0.000
Mn	0.000	0.000	0.001	0.002	0.000	0.000	0.000
Sr	0.005	0.005	0.021	0.006	0.006	0.006	0.006
Ba	0.000	0.000	0.015	0.000	0.000	0.000	0.000
Total Cat	5.025	4.994	4.608	5.012	5.011	5.013	5.001
mol %							
Albite	81	77	11	52	73	77	71
Anorthite	18	23	85	47	26	21	28
Orthoclase	0	0	4	1	1	2	1

APPENDIX C: plag. analyses; Danburg

Sample	enclave	enclave	enclave	enclave	enclave	enclave	enclave
Sumple	matrix	matrix	matrix	matrix	matrix	matrix	matrix
	matrix	matrix	maurx	matrix	matrix	matrix	matrix
SiO2	63.38	61.28	61.31	62.00	64.14	61.52	63.74
TiO2	0.00	0.03	0.03	0.00	0.00	0.02	0.04
A12O3	23.70	24.47	24.70	24.73	23.74	24.17	22.91
FeO	0.07	0.29	0.14	0.08	0.09	0.12	0.03
MnO	0.04	0.00	0.00	0.01	0.00	0.00	0.02
MgO	0.00	0.00	0.00	0.02	0.00	0.00	0.02
CaO	4.46	5.77	5.70	5.44	4.26	5.35	3.79
BaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SrO	0.22	0.21	0.25	0.24	0.26	0.24	0.24
Na2O	9.18	8.42	8.40	9.24	8.50	8.66	9.86
K2O	0.15	0.33	0.16	0.08	0.11	0.30	0.10
CalcTotal	101.20	100.80	100.69	101.84	101.10	100.38	100.75
formula			8 O basis				
calculations							
Si	2.776	2.712	2.711	2.713	2.799	2.729	2.803
Al	1.223	1.276	1.287	1.276	1.221	1.264	1.187
Fe2	0.003	0.011	0.005	0.003	0.003	0.004	0.001
Mg	0.000	0.000	0.000	0.001	0.000	0.000	0.001
Ca	0.209	0.274	0.270	0.255	0.199	0.254	0.179
Na	0.780	0.722	0.720	0.784	0.719	0.745	0.841
Κ	0.008	0.019	0.009	0.004	0.006	0.017	0.006
Ti	0.000	0.001	0.001	0.000	0.000	0.001	0.001
Mn	0.001	0.000	0.000	0.000	0.000	0.000	0.001
Sr	0.006	0.005	0.006	0.006	0.007	0.006	0.006
Ba	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total Cat	5.006	5.020	5.009	5.043	4.954	5.020	5.025
mol %							
Albite	78	71	72	75	78	73	82
Anorthite	21	27	27	24	22	25	17
Orthoclase	1	2	1	0	1	2	1

APPENDIX C: plag. analyses; Danburg (DG), Sandy Hill (SH), & mafic enclaves (E)

(DO), Salidy I	$\lim (311), \alpha$						
Sample	enclave	enclave	enclave	enclave	enclave	106 E	106 E
	matrix	matrix	matrix	matrix	matrix	matrix	matrix
						core	rim
SiO2	63.73	61.28	62.25	62.29	62.77	63.27	62.10
TiO2	0.00	0.00	0.00	0.04	0.02	0.00	0.00
Al2O3	22.88	24.29	23.83	23.86	23.35	22.95	23.91
FeO	0.13	0.06	0.18	0.12	0.14	0.11	0.12
MnO	0.04	0.03	0.00	0.03	0.00	0.00	0.00
MgO	0.00	0.02	0.01	0.00	0.00	0.00	0.02
CaO	3.72	5.72	5.14	5.00	4.58	3.50	4.66
BaO	0.00	0.00	0.00	0.06	0.00	0.00	0.02
SrO	0.20	0.24	0.21	0.22	0.23	•	•
Na2O	9.59	8.47	9.14	8.61	9.00	9.74	9.21
K2O	0.03	0.15	0.22	0.30	0.57	0.06	0.09
CalcTotal	100.32	100.26	100.98	100.53	100.66	99.63	100.13
formula			8 O basis				
calculations							
Si	2.810	2.721	2.745	2.753	2.773	2.805	2.751
Al	1.189	1.271	1.238	1.243	1.216	1.199	1.248
Fe2	0.005	0.002	0.007	0.004	0.005	0.004	0.004
Mg	0.000	0.001	0.001	0.000	0.000	0.000	0.001
Ca	0.176	0.272	0.243	0.237	0.217	0.166	0.221
Na	0.820	0.729	0.781	0.738	0.771	0.837	0.791
Κ	0.002	0.008	0.012	0.017	0.032	0.003	0.005
Ti	0.000	0.000	0.000	0.001	0.001	0.000	0.000
Mn	0.001	0.001	0.000	0.001	0.000	0.000	0.000
Sr	0.005	0.006	0.005	0.006	0.006	0.000	0.000
Ba	0.000	0.000	0.000	0.001	0.000	0.000	0.000
Total Cat	5.007	5.012	5.033	5.001	5.020	5.016	5.023
mol %							
Albite	82	72	75	74	76	83	78
Anorthite	18	27	23	24	21	17	22
Orthoclase	0	1	1	2	3	0	1

APPENDIX C: plag. analyses; Danburg (DG), Sandy Hill (SH), & mafic enclaves (E)

(DO), Sundy 1	(on), c						
Sample	106 E	DG105					
	1 1		1 1	1 1	1 1	1 1	
	lg. pheno						
<u> </u>	core	rim	rım		core	interm.	core
SiO2	61.99	62.32	61.94	59.16	60.58	60.06	56.98
TiO2	0.04	0.00	0.00	0.03	0.03	0.02	0.04
Al2O3	24.49	23.83	24.31	24.61	24.47	24.95	27.30
FeO	0.28	0.23	0.10	0.16	0.11	0.11	0.11
MnO	0.00	0.00	0.06	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.01	0.01
CaO	5.40	5.07	5.22	5.72	5.78	6.07	8.83
BaO	0.00	0.04	0.00	0.08	0.00	0.00	0.02
SrO	•	•	•	•	•	•	•
Na2O	8.24	8.52	8.77	7.79	8.91	8.14	6.58
K2O	0.22	0.20	0.18	0.30	0.12	0.12	0.22
CalcTotal	100.66	100.21	100.58	97.85	100.00	99.48	100.09
formula			8 O basis				
calculations							
Si	2.733	2.758	2.735	2.690	2.700	2.687	2.555
Al	1.272	1.243	1.265	1.319	1.286	1.315	1.443
Fe2	0.010	0.009	0.004	0.006	0.004	0.004	0.004
Mg	0.000	0.000	0.000	0.000	0.000	0.001	0.001
Ca	0.255	0.240	0.247	0.279	0.276	0.291	0.424
Na	0.704	0.731	0.751	0.687	0.770	0.706	0.572
K	0.012	0.011	0.010	0.017	0.007	0.007	0.013
Ti	0.001	0.000	0.000	0.001	0.001	0.001	0.001
Mn	0.000	0.000	0.002	0.000	0.000	0.000	0.000
Sr	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ba	0.000	0.001	0.000	0.001	0.000	0.000	0.000
Total Cat	4.988	4.992	5.013	5.001	5.044	5.011	5.014
mol %							
Albite	72	74	74	70	73	70	57
Anorthite	26	24	25	28	26	29	42
Orthoclase	1	1	1	2	1	1	1

APPENDIX C: plag. analyses; Danburg (DG), Sandy Hill (SH), & mafic enclaves (E)

APPE	NDIX	C: pl	lag. a	ınaly	/ses; []	Danburg	5
(\mathbf{DC})	Candra	TT:11	(CIT)	ν <i>Ο</i> _	fia	a	

(DG), Sandy	Hill (SH), &	k mafic en	claves (E)				
Sample	DG105	DG105	DG105	DG105	DG105	DG105	DG105
	XA	XA	XA	XA	XA	XA	XA
	lg. pheno	lg. pheno	lg. pheno	lg. pheno	lg. pheno	lg. pheno	lg. pheno
	interm.	interm.	rim	rim	seived c.	core	interm.
SiO2	56.49	56.83	59.77	62.11	62.11	56.94	60.56
TiO2	0.06	0.03	0.00	0.00	0.05	0.05	0.00
Al2O3	27.77	27.80	24.38	24.10	23.29	26.98	24.96
FeO	0.13	0.18	0.09	0.23	0.18	0.17	0.04
MnO	0.05	0.00	0.00	0.00	0.03	0.00	0.02
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	9.46	8.89	5.71	4.87	4.90	8.50	5.88
BaO	0.06	0.03	0.02	0.06	0.00	0.04	0.00
SrO	•	•	•	•	•	•	•
Na2O	6.23	6.32	8.44	8.93	8.52	6.80	8.41
K2O	0.14	0.18	0.33	0.36	0.29	0.13	0.06
CalcTotal	100.39	100.26	98.74	100.66	99.37	99.61	99.93
formula			8 O basis				
calculations							
Si	2.530	2.543	2.698	2.743	2.771	2.565	2.695
Al	1.466	1.466	1.297	1.254	1.224	1.432	1.309
Fe2	0.005	0.007	0.003	0.008	0.007	0.006	0.001
Mg	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ca	0.454	0.426	0.276	0.230	0.234	0.410	0.280
Na	0.541	0.548	0.739	0.765	0.737	0.594	0.726
Κ	0.008	0.010	0.019	0.020	0.017	0.007	0.003
Ti	0.002	0.001	0.000	0.000	0.002	0.002	0.000
Mn	0.002	0.000	0.000	0.000	0.001	0.000	0.001
Sr	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ba	0.001	0.001	0.000	0.001	0.000	0.001	0.000
Total Cat	5.009	5.002	5.032	5.022	4.992	5.018	5.015
mol %							
Albite	54	56	71	75	75	59	72
Anorthite	45	43	27	23	24	41	28
Orthoclase	1	1	2	2	2	1	0

APPE	NDI	Х	C: pl	lag.	ana	aly	ses; I	Danburg	
	C	1	T T 11	(OT)	r \	0	C*	1	

(DG), Sandy	Hill (SH), &	k mafic en	claves (E)				
Sample	DG105	DG105	DG105	DG105	DG105	DG105	DG105
	XA	XA	XA	XA	XA	XA	XA
	lg. pheno	lg. pheno	lg. pheno	lg. pheno	lg. pheno	lg. pheno	lg. pheno
	rim	seived c.	interm.	core	rim	core	rim
SiO2	63.19	59.08	60.48	61.33	62.62	57.11	60.40
TiO2	0.00	0.03	0.01	0.06	0.04	0.06	0.03
Al2O3	23.20	27.42	25.76	23.98	22.85	25.80	23.40
FeO	0.08	0.08	0.21	0.13	0.13	0.24	0.20
MnO	0.00	0.00	0.02	0.01	0.00	0.05	0.00
MgO	0.00	0.03	0.02	0.00	0.00	0.00	0.00
CaO	3.89	8.26	6.34	5.12	3.95	7.41	4.79
BaO	0.04	0.02	0.00	0.04	0.00	0.13	0.06
SrO	•	•	•	•	•	•	•
Na2O	9.36	7.07	8.27	8.40	8.84	7.05	8.67
K2O	0.24	0.13	0.14	0.20	0.18	0.25	0.23
CalcTotal	100.00	102.12	101.25	99.27	98.61	98.10	97.78
formula			8 O basis				
calculations							
Si	2.795	2.589	2.664	2.740	2.803	2.609	2.744
Al	1.209	1.416	1.337	1.263	1.205	1.389	1.253
Fe2	0.003	0.003	0.008	0.005	0.005	0.009	0.008
Mg	0.000	0.002	0.001	0.000	0.000	0.000	0.000
Ca	0.184	0.388	0.299	0.245	0.189	0.363	0.233
Na	0.803	0.601	0.706	0.728	0.767	0.624	0.764
Κ	0.014	0.007	0.008	0.011	0.010	0.015	0.013
Ti	0.000	0.001	0.000	0.002	0.001	0.002	0.001
Mn	0.000	0.000	0.001	0.000	0.000	0.002	0.000
Sr	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ba	0.001	0.000	0.000	0.001	0.000	0.002	0.001
Total Cat	5.009	5.006	5.024	4.996	4.982	5.014	5.017
mol %							
Albite	80	60	70	74	79	62	76
Anorthite	18	39	30	25	20	36	23
Orthoclase	1	1	1	1	1	1	1

(DO), buildy	$\min(\operatorname{DH}), c$						
Sample	enclave	enclave	enclave	enclave	205 E	205 E	205 E
-	inclusion	inclusion	inclusion	inclusion	core;	rim; incl.	core;
					incl.		incl.
	in Ksp	in Ksp	in Ksp	in Ksp	in Ksp	in Ksp	in Ksp
SiO2	62.12	67.69	62.24	61.35	58.04	62.29	61.34
TiO2	0.00	0.02	0.02	0.05	0.04	0.03	0.00
A12O3	24.20	20.82	24.28	24.67	25.83	24.26	23.50
FeO	0.13	0.02	0.14	0.21	0.10	0.09	0.07
MnO	0.00	0.00	0.01	0.00	0.05	0.03	0.03
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	5.13	1.05	5.28	5.95	7.68	4.90	4.92
BaO	0.03	0.00	0.00	0.00	0.00	0.04	0.00
SrO	0.22	0.33	0.19	0.24	•	•	•
Na2O	8.98	12.15	9.24	8.70	7.10	8.94	8.36
K2O	0.13	0.06	0.16	0.25	0.12	0.11	0.08
CalcTotal	100.94	102.14	101.56	101.42	98.96	100.69	98.30
formula			8 O basis				
calculations			0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0				
Si	2.737	2.921	2.730	2.702	2.622	2.744	2.761
Al	1.257	1.059	1.255	1.280	1.375	1.259	1.247
Fe2	0.005	0.001	0.005	0.008	0.004	0.003	0.003
Mg	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ca	0.242	0.049	0.248	0.281	0.372	0.231	0.237
Na	0.767	1.017	0.786	0.743	0.622	0.764	0.730
Κ	0.007	0.003	0.009	0.014	0.007	0.006	0.005
Ti	0.000	0.001	0.001	0.002	0.001	0.001	0.000
Mn	0.000	0.000	0.000	0.000	0.002	0.001	0.001
Sr	0.006	0.008	0.005	0.006	0.000	0.000	0.000
Ba	0.001	0.000	0.000	0.000	0.000	0.001	0.000
Total Cat	5.022	5.059	5.039	5.035	5.004	5.010	4.983
mol %							
Albite	75	95	75	72	62	76	75
Anorthite	24	5	24	27	37	23	24
Orthoclase	1	0	1	1	1	1	0

APPENDIX	C: plag.	analyses;	Danburg
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(DG), Sandy Hill (SH), & mafic enclaves (E)

APPE	NDIX	C: plag.	analyses;	Danburg	
(\mathbf{DG})	Sandy	Lill (SI	I) & maf	ic anclavas	(\mathbf{F})

(DG), Sandy H	$\frac{1111(SH), \&}{205 F}$	$\frac{\text{mattern}}{205 \text{ F}}$	$\frac{\text{claves (E)}}{205 \text{ F}}$	DG D1	DG D1	DG D3	DG D3
Sample	203 E	205 E	205 L	ropokivi	ropokivi	ropokivi	ropokivi
	incl	incl	11111, 11IC1.	таракти	таракти	таракти	таракти
	in Ken	in Ksn	in Ksn	rim	rim	rim	rim
SiO2	<u>61 78</u>	60.92	61.16	62.78	63.30	63.11	69 77
5102 TiO2	01.78	0.92	0.01	02.78	0.00	0.00	0.00
A12O3	24.17	24.46	23.86	26.50	23.16	22 71	20.23
FeO	0.15	0.12	25.80	20.59	0.08	0.03	20.23
MnO	0.13	0.00	0.00	0.00	0.00	0.03	0.00
ΜσΟ	0.00	0.00	0.03	0.00	0.00	0.01	0.00
$\Gamma_{2}O$	5 25	5.00	5 33	0.03 4 48	4 15	3.88	0.00
BaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SrO	•	•	•	0.16	0.21	0.19	0.17
Na2O	8.55	7.92	8.50	9.30	9.33	9.50	11.18
K2O	0.09	0.15	0.13	0.06	0.09	0.12	0.09
CalcTotal	100.05	99.51	99.13	103.49	100.32	99.55	101.96
			,,				
formula			8 O basis				
calculations							
Si	2.739	2.718	2.738	2.691	2.793	2.806	2.987
Al	1.263	1.286	1.259	1.343	1.205	1.190	1.021
Fe2	0.006	0.004	0.003	0.002	0.003	0.001	0.003
Mg	0.000	0.000	0.002	0.002	0.000	0.000	0.000
Ca	0.249	0.284	0.256	0.206	0.196	0.185	0.021
Na	0.735	0.685	0.738	0.773	0.798	0.819	0.928
Κ	0.005	0.009	0.007	0.003	0.005	0.007	0.005
Ti	0.001	0.000	0.000	0.001	0.000	0.000	0.000
Mn	0.002	0.000	0.001	0.000	0.000	0.000	0.000
Sr	0.000	0.000	0.000	0.004	0.005	0.005	0.004
Ba	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T 1 C	1 0 0 0	1.000	5 00 5		7 00 C	5 0 1 0	1000
Total Cat	4.999	4.986	5.005	5.025	5.006	5.012	4.969
mol %							
Albite	74	70	74	79	80	81	97
Anorthite	25	29	26	21	20	18	2
Orthoclase	1	1	1	0	1	1	1

APPE	NDIX	C: plag.	analyses	; Danburg	
(\mathbf{DG})	Sandy	Hill (SF	I) & maf	ic enclaves ((\mathbf{F})

(DG), Sandy I	HIII (SH), &	manc enc	laves (E)	
Sample	DG D3	DG D3	DG D3	DG D3
	rapakivi	Ksp	Ksp	Ksp incl.
	rim			in plag
SiO2	69.19	64.38	64.09	64.84
TiO2	0.00	0.03	0.00	0.04
Al2O3	20.75	18.52	18.44	18.75
FeO	0.01	0.10	0.07	0.02
MnO	0.00	0.00	0.06	0.02
MgO	0.00	0.00	0.00	0.01
CaO	0.42	0.00	0.03	0.03
BaO	0.00	0.59	0.40	0.33
SrO	0.14	0.21	0.18	0.18
Na2O	10.33	0.71	0.53	0.71
K2O	0.11	15.88	15.99	16.02
CalcTotal	100.95	100.42	99.79	100.95
formula			8 O basis	
calculations				
Si	2.981	2.981	2.983	2.979
Al	1.054	1.011	1.011	1.015
Fe2	0.000	0.004	0.003	0.001
Mg	0.000	0.000	0.000	0.001
Ca	0.019	0.000	0.001	0.001
Na	0.863	0.064	0.048	0.063
Κ	0.006	0.938	0.949	0.939
Ti	0.000	0.001	0.000	0.001
Mn	0.000	0.000	0.002	0.001
Sr	0.003	0.006	0.005	0.005
Ba	0.000	0.011	0.007	0.006
Total Cat	4.927	5.014	5.010	5.013
mol %				
Albite	97	6	5	6
Anorthite	2	0	0	0
Orthoclase	1	94	95	94

APPENDIX D: BIOTITE MICROPROBE ANALYSES

	DG101 E	DG101 E	DG101 E	DG101 E	DG101 E	DG200 LE
	rim	rim				
SiO2	37.64	37.81	38.05	38.12	38.16	37.03
Al2O3	14.20	13.81	13.94	13.66	13.87	14.30
TiO2	2.29	2.23	2.47	2.68	2.11	2.42
FeO ^t	16.87	17.14	17.98	17.20	17.33	18.15
FeO	12.23	12.43	13.04	12.47	12.56	14.19
Fe2O3	5.15	5.24	5.49	5.26	5.29	4.40
MnO	0.59	0.64	0.55	0.60	0.58	0.44
MgO	13.18	13.55	12.98	13.83	13.97	11.78
CaO	0.01	0.00	0.00	0.00	0.02	0.01
BaO	0.16	0.00	0.10	0.17	0.06	•
Na2O	0.04	0.02	0.03	0.08	0.03	0.07
K2O	9.49	9.60	7.83	9.43	9.20	8.68
Cl	0.05	0.06	0.06	0.05	0.06	0.10
F	2.22	2.25	2.28	2.43	2.30	1.67
analytical total	97.25	97.63	96.82	98.78	98.22	95.09
H2O (calc)	2.92	2.91	2.89	2.87	2.92	3.09
SUM	100.17	100.55	98.71	101.65	101.13	99.18
O = Cl, F	0.95	0.96	0.97	1.03	0.98	0.73
TOTAL	99.22	99.59	98.74	100.62	100.15	97.45
formula calculatio	ons		22 O basis			
Si	5.664	5.674	5.715	5.663	5.681	5.681
Al (IV)	2.336	2.326	2.285	2.337	2.319	2.319
Al (VI)	0.185	0.119	0.186	0.057	0.118	0.27
Ti	0.259	0.252	0.279	0.299	0.236	0.279
Fe +3	0.583	0.592	0.62	0.588	0.593	0.508
Fe +2	1.539	1.56	1.638	1.55	1.564	1.821
Mn	0.075	0.081	0.07	0.075	0.073	0.057
Mg	2.956	3.03	2.906	3.062	3.1	2.694
Ca	0.002	0	0	0	0.003	0.002
Ba	0.009	0	0.006	0.01	0.004	0
Na	0.012	0.006	0.009	0.023	0.009	0.021
Κ	1.821	1.838	1.5	1.787	1.747	1.699
Cl	0.013	0.015	0.015	0.013	0.015	0.026
F	1.056	1.068	1.083	1.141	1.083	0.81
OH (calc)	2.931	2.917	2.902	2.846	2.902	3.164
oct. cations	5.598	5.635	5.7	5.632	5.684	5.63
int. cations	1.844	1.843	1.515	1.82	1.762	1.721
$Mg/(Mg + Fe^{tot})$	0.582	0.585	0.563	0.589	0.59	0.536
X(Mg)	0.528	0.538	0.51	0.544	0.545	0.478
X(Sid)	0.203	0.18	0.192	0.166	0.174	0.24
X(Ann)	0.269	0.283	0.298	0.291	0.281	0.281

APPENDIX D: Microprobe analyses of biotite; Danburg pluton and mafic enclaves

	DG200 LE	DG200 LE	DG200 LE	DG200 LE	DG200 LE	DG202sch
						inclusion
SiO2	37.28	37.61	38.22	38.48	38.95	37.58
Al2O3	13.86	13.68	13.35	14.13	14.05	14.10
TiO2	2.84	2.65	2.86	2.05	2.74	2.97
FeO ^t	18.15	17.27	18.15	16.80	16.73	18.23
FeO	14.19	13.51	14.19	13.14	13.08	13.13
Fe2O3	4.40	4.18	4.40	4.07	4.05	5.67
MnO	0.52	0.54	0.54	0.50	0.51	0.51
MgO	11.73	12.06	12.77	12.52	12.59	12.20
CaO	0.05	0.00	0.00	0.02	0.04	0.00
BaO	•	•	•	•	•	0.19
Na2O	0.15	0.07	0.07	0.03	0.03	0.03
K2O	8.58	8.63	8.40	8.42	8.18	9.73
Cl	0.09	0.07	0.06	0.04	0.06	0.07
F	1.58	1.60	2.40	1.74	1.69	1.61
analytical total	95.27	94.60	97.26	95.14	95.97	97.79
H2O (calc)	3.15	3.13	2.83	3.12	3.19	3.22
SUM	98.42	97.73	100.09	98.26	99.16	101.01
O = Cl, F	0.07	0.69	1.02	0.74	0.73	0.69
TOTAL	97.73	94.07	99.06	97.52	98.43	100.32
formula			22 O basis			
calculations						
Si	5.704	5.768	5.754	5.832	5.834	5.628
Al (IV)	2.296	2.232	2.246	2.168	2.166	2.372
Al (VI)	0.206	0.244	0.126	0.36	0.317	0.12
Ti	0.327	0.306	0.324	0.234	0.309	0.335
Fe +3	0.507	0.482	0.498	0.464	0.456	0.639
Fe +2	1.816	1.733	1.787	1.666	1.639	1.645
Mn	0.067	0.07	0.069	0.064	0.065	0.065
Mg	2.675	2.757	2.866	2.828	2.81	2.723
Ca	0.008	0	0	0.003	0.006	0
Ba	0	0	0	0	0	0.011
Na	0.044	0.021	0.02	0.009	0.009	0.009
K	1.674	1.688	1.613	1.628	1.563	1.859
Cl	0.023	0.018	0.015	0.01	0.015	0.018
F	0.764	0.776	1.143	0.834	0.8	0.762
OH (calc)	3.212	3.206	2.842	3.156	3.184	3.22
oct. cations	5.598	5.592	5.67	5.616	5.596	5.527
int. cations	1.727	1.709	1.634	1.64	1.578	1.879
$Mg/(Mg + Fe^{tot})$	0.535	0.554	0.556	0.57	0.573	0.544
X(Mg)	0.478	0.493	0.505	0.504	0.502	0.493
X(Sid)	0.215	0.194	0.162	0.196	0.185	0.215
X(Ann)	0.307	0.313	0.332	0.3	0.313	0.292

APPENDIX D (cont.): Microprobe analyses of biotite; Danburg pluton and mafic enclaves

ont.): Micro	probe analys	es of			
DG202sch	DG202sch	DG202sch	DG202sch	DG202sch	DG202sch
inclusion	inclusion	inclusion			inclusion
37.78	37.93	38.11	38.33	37.92	38.45
14.19	14.05	14.33	14.51	13.69	14.68
2.55	2.73	2.58	2.63	2.63	2.38
17.39	18.59	18.03	18.10	17.80	16.64
12.52	13.38	12.98	13.03	12.82	11.98
5.41	5.78	5.61	5.63	5.54	5.18
0.51	0.60	0.66	0.61	0.52	0.71
12.65	12.67	12.84	13.20	13.50	12.53
0.00	0.00	0.00	0.00	0.00	0.02
0.00	0.14	0.11	0.11	0.18	0.14
0.03	0.06	0.07	0.06	0.08	0.06
9.43	9.56	9.57	9.55	9.33	9.09
0.06	0.06	0.07	0.05	0.06	0.06
1.59	2.03	2.18	1.88	2.17	2.00
96.72	99.00	99.11	99.59	98.44	97.28
3.22	3.06	3.00	3.18	2.98	3.06
99.94	102.05	102.11	102.77	101.42	100.34
0.68	0.87	0.93	0.80	0.93	0.86
99.26	101.18	101.17	101.97	100.49	99.48
		22 O basis			
5.676	5.632	5.643	5.624	5.649	5.733
2.324	2.368	2.357	2.376	2.351	2.267
0.192	0.094	0.148	0.137	0.056	0.316
0.288	0.305	0.287	0.29	0.295	0.267
0.612	0.646	0.625	0.622	0.621	0.581

APPENDIX D (cont.): Mid biotite; Danburg pluton and

SiO2

TiO2

FeO^t

FeO

Fe2O3 MnO

MgO CaO

BaO

K2O

Cl

F

Na2O

Al2O3

analytical total	96.72	99.00	99.11	99.59	98.44	97.28
H2O (calc)	3.22	3.06	3.00	3.18	2.98	3.06
SUM	99.94	102.05	102.11	102.77	101.42	100.34
O = Cl, F	0.68	0.87	0.93	0.80	0.93	0.86
TOTAL	99.26	101.18	101.17	101.97	100.49	99.48
formula		2	2 O basis			
calculations						
Si	5.676	5.632	5.643	5.624	5.649	5.733
Al (IV)	2.324	2.368	2.357	2.376	2.351	2.267
Al (VI)	0.192	0.094	0.148	0.137	0.056	0.316
Ti	0.288	0.305	0.287	0.29	0.295	0.267
Fe +3	0.612	0.646	0.625	0.622	0.621	0.581
Fe +2	1.574	1.662	1.608	1.599	1.598	1.494
Mn	0.065	0.075	0.083	0.076	0.066	0.09
Mg	2.833	2.804	2.834	2.887	2.998	2.785
Ca	0	0	0	0	0	0.003
Ba	0	0.008	0.006	0.006	0.011	0.008
Na	0.009	0.017	0.02	0.017	0.023	0.017
Κ	1.807	1.811	1.808	1.787	1.773	1.729
Cl	0.015	0.015	0.018	0.012	0.015	0.015
F	0.755	0.953	1.021	0.872	1.022	0.943
OH (calc)	3.229	3.032	2.962	3.115	2.963	3.042
oct. cations	5.564	5.587	5.584	5.61	5.633	5.333
int. cations	1.816	1.836	1.834	1.811	1.807	1.758
$Mg/(Mg + Fe^{tot})$	0.565	0.549	0.559	0.565	0.575	0.573
X(Mg)	0.509	0.502	0.507	0.515	0.532	0.503
X(Sid)	0.209	0.203	0.21	0.211	0.175	0.222
X(Ann)	0.282	0.295	0.282	0.274	0.293	0.275

U _	DG202sch	DG202sch	DG202sch	D1	D1	DG 301
SiO2	38.55	38.81	39.35	36.04	38.02	37.22
Al2O3	13.62	14.39	13.37	13.66	14.32	13.94
TiO2	1.66	2.67	1.33	2.51	2.67	2.59
FeO ^t	15.75	18.12	15.06	16.42	18.03	18.18
FeO	11.34	13.05	10.84	11.61	12.75	12.85
Fe2O3	4.90	5.64	4.68	5.35	5.87	5.92
MnO	0.50	0.58	0.53	0.45	0.69	0.43
MgO	15.90	13.53	16.82	11.76	12.97	12.38
CaO	0.03	0.00	0.01	0.03	0.04	0.07
BaO	0.06	0.05	0.08	0.04	0.19	0.04
Na2O	0.03	0.06	0.06	0.02	0.07	0.03
K2O	9.59	8.30	9.50	8.32	9.56	9.75
Cl	0.05	0.05	0.05	0.10	0.05	0.09
F	2.29	2.20	2.62	1.62	2.25	2.29
analytical total	98.52	99.32	99.25	91.50	99.45	97.60
H2O (calc)	2.96	3.04	2.84	2.99	2.98	2.86
SUM	101.48	102.37	102.08	94.50	102.43	100.46
O = Cl, F	0.98	0.94	1.11	0.70	0.96	0.98
TOTAL	100.51	101.43	100.97	93.80	101.47	99.47
formula			22 O basis			
calculations						
Si	5.69	5.676	5.756	5.701	5.618	5.624
Al (IV)	2.31	2.324	2.244	0.2299	2.382	2.376
Al (VI)	0.063	0.16	0.064	0.252	0.115	0.11
Ti	0.184	0.294	0.146	0.299	0.297	0.294
Fe +3	0.544	0.621	0.515	0.637	0.653	0.673
Fe +2	1.4	1.597	1.326	1.536	1.576	1.624
Mn	0.063	0.072	0.066	0.06	0.086	0.055
Mg	3.498	2.949	3.667	2.773	2.856	2.788
Ca	0.005	0	0.002	0.005	0.006	0.011
Ba	0.003	0.003	0.005	0.002	0.011	0.002
Na	0.009	0.017	0.017	0.006	0.02	0.009
Κ	1.806	1.548	1.773	1.679	1.802	1.879
Cl	0.013	0.012	0.012	0.027	0.013	0.023
F	1.069	1.017	1.212	0.81	1.051	1.094
OH (calc)	2.919	2.97	2.776	3.163	2.936	2.883
oct. cations	5.752	5.692	5.785	5.556	5.583	5.545
int. cations	1.822	1.568	1.796	1.693	1.839	1.902
$Mg/(Mg + Fe^{tot})$	0.643	0.571	0.666	0.561	0.562	0.548
X(Mg)	0.608	0.518	0.634	0.499	0.512	0.503
X(Sid)	1.35	0.197	0.106	0.219	0.209	0.21
X(Ann)	0.257	0.285	0.26	0.282	0.279	0.288

APPENDIX D (cont.): Microprobe analyses of biotite; Danburg pluton and mafic enclaves

<u>81</u>	DG 301	DG 306	DG 306	DG 306	DG 306	DG 306
SiO2	37.82	36 75	36.91	37 14	37 38	37 54
A12O3	14 49	13 55	13 43	13.64	13 71	13.52
TiO2	2 31	2 58	2 49	2 58	2 57	2 75
FeO ^t	17.21	18 29	17.85	18 49	18 47	17 97
FeO	12.17	12.93	12.62	13.07	13.06	12 70
Fe2O3	5.60	5 95	5.81	6.02	6.01	5.85
MnO	0.64	0.70	0.58	0.62	0.52	0.47
MgO	13 20	12.38	12.74	13.12	12.91	13.20
CaO	0.08	0.08	0.04	0.06	0.11	0.04
BaO	0.08	0.00	0.03	0.08	0.08	0.07
Na2O	0.06	0.00	0.08	0.10	0.06	0.10
K20	9.61	9.76	10.00	9.85	9.90	9.99
Cl	0.04	0.05	0.06	0.07	0.05	0.05
F	2.31	2.13	2.18	2.04	2.17	2.30
analytical total	98.41	96.93	96.97	98.46	98.53	98.58
H2O (calc)	2.92	2.89	2.89	3.01	2.96	2.90
SUM	101.33	99.19	99.86	101.47	101.49	101.48
O = Cl. F	0.98	0.91	0.93	0.87	0.92	0.98
TOTAL	100.35	98.29	98.92	100.60	100.56	100.50
formula	100.00	70.27	22.0 basis	100.00	100100	100100
calculations		-				
Si	5.63	5.623	5.622	5.572	5.602	5.619
Al (IV)	2.37	2.377	2.378	2.415	2.398	2.381
Al (VI)	0.176	0.07	0.036	0	0.026	0.007
Ti	0.259	0.297	0.285	0.291	0.29	0.31
Fe +3	0.627	0.685	0.666	0.68	0.678	0.659
Fe +2	1.516	1.655	1.608	1.64	1.637	1.59
Mn	0.081	0.009	0.075	0.088	0.066	0.06
Mg	2.929	3.823	2.892	2.934	2.884	2.945
Ca	0.013	0.013	0.007	0.01	0.018	0.006
Ba	0.005	0	0.002	0.005	0.005	0.004
Na	0.017	0.021	0.024	0.029	0.017	0.029
Κ	1.825	1.905	1.943	1.885	1.892	1.907
Cl	0.01	0.013	0.015	0.018	0.013	0.013
F	1.087	1.031	1.05	0.968	1.028	1.089
OH (calc)	2.903	2.957	2.935	3.014	2.959	2.899
oct. cations	5.586	5.539	5.562	5.619	5.58	5.57
int. cations	1.86	1.939	1.975	1.928	1.932	1.947
$Mg/(Mg + Fe^{tot})$	0.577	0.547	0.56	0.558	0.555	0.567
X(Mg)	0.524	0.51	0.52	0.522	0.517	0.529
X(Sid)	0.214	0.197	0.184	0.189	0.19	0.174
X(Ann)	0.261	0.294	0.296	0.289	0.293	0.297

APPENDIX D (cont.): Microprobe analyses of biotite; Danburg pluton and mafic enclaves

biotite, Dunburg p	maton and m	une energies				
¥	DG 306	DG2 FG	DG2 FG	DG2 FG	DG2 FG	DG2 FG
		core	rim	core	core	rim
SiO2	37.54	37.12	37.19	37.26	37.34	37.38
A12O3	14.17	14.11	14.26	14.19	13.87	13.86
TiO2	2.57	2.73	2.66	2.71	2.67	2.65
FeO ^t	18.01	18.50	17.56	18.56	18.33	17.83
FeO	12.73	13.95	13.24	13.99	13.82	13.44
Fe2O3	5.86	5.06	4.80	5.07	5.01	4.87
MnO	0.49	0.53	0.44	0.53	0.60	0.54
MgO	12.90	12.50	12.91	12.72	12.89	12.70
CaO	0.03	0.02	0.05	0.00	0.01	0.03
BaO	0.07	0.34	0.18	0.45	0.50	0.09
Na2O	0.05	0.05	0.06	0.08	0.04	0.08
K2O	9.85	9.91	9.62	9.43	9.54	9.73
Cl	0.05	0.03	0.05	0.04	0.04	0.03
F	2.14	1.79	1.79	1.84	1.90	1.96
analytical total	98.46	98.14	97.25	98.32	98.23	97.37
H2O (calc)	2.99	3.13	3.12	3.12	3.08	3.03
SUM	101.44	101.27	100.37	101.43	101.31	100.39
O = Cl, F	0.91	0.76	0.76	0.78	0.81	0.83
TOTAL	100.52	100.51	99.60	100.64	100.50	99.56
formula		2	2 O basis			
calculations						
Si	5.606	5.582	5.602	5.583	5.607	5.642
Al (IV)	2.394	2.418	2.398	2.417	2.393	2.358
Al (VI)	0.103	0.086	0.137	0.093	0.065	0.111
Ti	0.289	0.309	0.301	0.305	0.302	0.301
Fe +3	0.658	0.572	0.544	0.572	0.566	0.553
Fe +2	1.59	1.755	1.668	1.754	1.736	1.697
Mn	0.062	0.068	0.056	0.067	0.076	0.069
Mg	2.871	2.801	2.898	2.841	2.885	2.857
Ca	0.005	0.003	0.008	0	0.002	0.005
Ba	0.004	0.02	0.011	0.026	0.029	0.005
Na	0.014	0.015	0.018	0.023	0.012	0.023
Κ	1.876	1.901	1.848	1.802	1.827	1.873
Cl	0.013	0.008	0.013	0.01	0.01	0.008
F	1.011	0.851	0.853	0.872	0.902	0.935
OH (calc)	2.977	3.141	3.135	3.118	3.088	3.057
oct. cations	5.573	5.59	5.605	5.632	54.629	5.588
int. cations	1.9	1.939	1.885	1.852	1.87	1.907
$Mg/(Mg + Fe^{tot})$	0.561	0.546	0.567	0.55	0.556	0.559
X(Mg)	0.515	0.501	0.517	0.504	0.512	0.511
X(Sid)	0.209	0.22	0.218	0.219	0.2	0.2
X(Ann)	0.276	0.279	0.265	0.276	0.287	0.289

APPENDIX D (cont.): Microprobe analyses of biotite; Danburg pluton and mafic enclaves

olotile, Duilouig p	futon una m				
	DG2 FG	DG2 FG	DG2 FG	DG2 FG	DG2 FG
	rim	rim	rim	core	core
SiO2	37.39	37.54	37.60	37.71	37.92
Al2O3	13.95	14.69	14.43	13.82	13.79
TiO2	2.66	2.73	2.63	2.76	2.64
FeO ^t	18.11	18.09	18.11	18.51	18.87
FeO	13.65	13.64	13.65	13.96	14.23
Fe2O3	4.95	4.94	4.95	5.06	5.16
MnO	0.56	0.58	0.52	0.57	0.58
MgO	12.89	12.61	12.81	13.01	13.16
CaO	0.01	0.01	0.03	0.00	0.00
BaO	0.08	0.15	0.08	0.25	0.08
Na2O	0.05	0.06	0.04	0.05	0.07
K2O	9.73	9.85	9.94	9.69	9.85
Cl	0.04	0.05	0.04	0.06	0.05
F	1.90	1.74	1.87	1.78	1.88
<u>analytical total</u>	97.86	98.59	98.59	98.72	99.41
H2O (calc)	3.08	3.19	3.13	3.16	3.14
SUM	100.94	101.78	101.72	101.88	102.55
O = Cl, F	0.81	0.74	0.80	0.76	0.80
TOTAL	100.13	101.04	100.92	101.12	101.75
formula		2	22 O basis		
calculations					
Si	5.616	5.585	5.601	5.62	5.62
Al (IV)	2.384	2.415	2.399	2.38	2.38
Al (VI)	0.089	0.164	0.138	0.05	0.032
Ti	0.3	0.305	0.295	0.309	0.294
Fe +3	0.559	0.553	0.555	0.567	0.575
Fe +2	1.715	1.698	1.701	1.74	1.764
Mn	0.071	0.073	0.066	0.072	0.073
Mg	2.886	2.796	2.844	2.89	2.907
Ca	0.002	0.002	0.005	0	0
Ba	0.005	0.009	0.005	0.015	0.005
Na	0.015	0.017	0.012	0.014	0.02
Κ	1.864	1.869	1.889	1.842	1.862
Cl	0.01	0.013	0.01	0.015	0.013
F	0.902	0.819	0.881	0.839	0.881
OH (calc)	3.087	3.169	3.109	3.146	3.106
oct. cations	5.621	5.59	5.599	5.629	5.646
int. cations	1.885	1.897	1.91	1.871	1.887
$Mg/(Mg + Fe^{tot})$	0.559	0.554	0.558	0.556	0.554
X(Mg)	0.513	0.5	0.508	0.513	0.515
X(Sid)	0.203	0.238	0.223	0.191	0.186
X(Ann)	0.284	0.261	0.269	0.295	0.299

APPENDIX D (cont.): Microprobe analyses of biotite; Danburg pluton and mafic enclaves

APPENDIX E: AMPHIBOLE MICROPROBE ANALYSES

	DG 101 xa	DG 101 xa	DG 101 xa	DG 101 xa	DG 101 xa
	core	interior	rim	rim	rim
	0010				
SiO2	43.90	44.18	43.83	43.46	43.64
TiO2	1.35	1.27	0.92	1.44	0.86
Al2O3	8.31	8.13	8.54	8.26	8.94
Fe(t)(FeO)	18.12	18.13	18.74	18.05	17.80
MnO	0.85	0.84	0.74	0.77	0.89
MgO	10.80	10.73	10.45	10.51	10.49
CaO	11.43	11.36	11.62	11.41	11.68
Na2O	1.57	1.68	1.55	1.69	1.53
K2O	1.28	1.21	1.27	1.24	1.20
F	1.02	1.06	1.05	1.07	1.03
Cl	0.13	0.12	0.11	0.13	0.07
BaO	0.00	0.00	0.00	0.00	0.00
Sum(ox)	98.28	98.22	98.33	97.53	97.67
Formula					
calculations			23 O basis		
sum cats	15.773	15.765	15.794	15.784	15.766
Si	6.599	6.642	6.576	6.597	6.541
Ti	0.153	0.144	0.104	0.164	0.097
Al	1.472	1.441	1.510	1.478	1.579
Fe3+	0.583	0.571	0.753	0.537	0.908
Fe2+	1.695	1.709	1.598	1.754	1.323
Mn	0.108	0.107	0.094	0.099	0.113
Mg	2.420	2.405	2.337	2.378	2.344
Ca	1.841	1.830	1.868	1.856	1.876
Na	0.458	0.490	0.451	0.497	0.445
Κ	0.245	0.232	0.243	0.240	0.229
Ba	0.000	0.000	0.000	0.000	0.000
F	0.485	0.504	0.498	0.514	0.488
Cl	0.033	0.031	0.028	0.033	0.018
OH	1.482	1.465	1.474	1.453	1.494
ox+H2O	99.77	99.69	99.82	98.97	99.17
Fe3/Fe(t)	0.256	0.250	0.320	0.234	0.407
sum[vi+iv]	13.029	13.018	12.973	13.007	12.905
sum[vi]	5.029	5.018	4.973	5.007	4.905

APPENDIX E: Amphibole analyses; Danburg gr. (DG, sch) & mafic enclaves (E)
	DG 101 xa	DG 101 xa	DG 101 xa	DG 101 xa	DG 101 xa
	interior	core		core	rim
SiO2	43.81	43.76	43.61	42.97	44.41
TiO2	0.96	0.95	0.82	0.92	0.86
A12O3	8.30	8.28	8.73	8.43	8.26
Fe(t)(FeO)	17.97	18.60	18.13	18.04	17.42
MnO	0.89	0.74	0.78	0.86	0.88
MgO	10.72	10.65	10.47	10.61	10.99
CaO	11.52	11.36	11.67	11.60	11.72
Na2O	1.49	1.69	1.46	1.36	1.55
K2O	1.27	1.29	1.25	1.14	1.17
F	1.09	1.09	0.94	1.05	1.08
Cl	0.08	0.11	0.06	0.04	0.08
BaO	0.00	0.00	0.00	0.00	0.00
Sum(ox)	97.61	98.02	97.50	96.56	97.93
Formula					
calculations			23 O basis		
sum cats	15.772	15.823	15.771	15.777	15.749
Si	6.608	6.604	6.559	6.549	6.644
Ti	0.109	0.108	0.093	0.105	0.097
Al	1.476	1.473	1.547	1.514	1.456
Fe3+	0.718	0.643	0.872	0.787	0.756
Fe2+	1.549	1.704	1.408	1.513	1.423
Mn	0.114	0.095	0.099	0.111	0.112
Mg	2.410	2.396	2.347	2.410	2.451
Ca	1.862	1.837	1.880	1.894	1.879
Na	0.436	0.494	0.426	0.402	0.450
Κ	0.244	0.248	0.240	0.222	0.223
Ba	0.000	0.000	0.000	0.000	0.000
F	0.520	0.520	0.447	0.506	0.511
Cl	0.020	0.028	0.015	0.010	0.020
OH	1.460	1.452	1.538	1.484	1.469
ox+H2O	99.07	99.47	99.05	98.03	99.42

Fe3/Fe(t)

sum[vi]

sum[vi+iv]

0.317

12.984

4.984

0.274

13.022

5.022

0.382

12.926

4.926

0.342

12.989

4.989

0.347

12.938

4.938

APPENDIX E: Amphibole analyses; Danburg gr. (DG, sch) & mafic enclaves (E)

	DG 101 xa	DG 101 xa	DG 101 xa	DG 101 xa	DG 101 xa
	rim	core	rim	core	rim
SiO2	44.63	44.19	44.12	44.05	43.45
TiO2	0.87	0.89	0.88	0.86	0.86
Al2O3	8.56	8.64	8.61	8.78	8.91
Fe(t)(FeO)	17.58	17.96	17.42	18.01	17.29
MnO	0.74	0.73	0.80	0.86	0.78
MgO	11.13	10.91	10.96	11.00	10.58
CaO	11.75	11.77	11.57	11.68	11.55
Na2O	1.42	1.42	1.50	1.62	1.45
K2O	1.17	1.19	1.21	1.20	1.24
F	1.07	1.09	1.13	1.00	0.91
Cl	0.10	0.06	0.07	0.03	0.05
BaO	0.00	0.00	0.00	0.00	0.00
Sum(ox)	98.53	98.37	97.77	98.66	96.67
Formula					
calculations			23 O basis		
sum cats	15.722	15.748	15.745	15.805	15.741
Si	6.614	6.580	6.598	6.551	6.567
Ti	0.097	0.100	0.099	0.096	0.098
Al	1.495	1.516	1.517	1.539	1.587
Fe3+	0.852	0.841	0.843	0.802	0.839
Fe2+	1.327	1.395	1.335	1.438	1.347
Mn	0.093	0.092	0.101	0.108	0.100
Mg	2.458	2.421	2.443	2.438	2.383
Ca	1.866	1.878	1.854	1.861	1.870
Na	0.408	0.410	0.435	0.467	0.425
Κ	0.221	0.226	0.231	0.228	0.239
Ba	0.000	0.000	0.000	0.000	0.000
F	0.501	0.513	0.534	0.470	0.435
Cl	0.025	0.015	0.018	0.008	0.013
OH	1.473	1.472	1.448	1.522	1.552
ox+H2O	100.03	99.86	99.23	100.20	98.22
Fe3/Fe(t)	0.391	0.376	0.387	0.358	0.384
sum[vi+iv]	12.936	12.946	12.937	12.973	12.920
sum[vi]	4.936	4.946	4.937	4.973	4.920

APPENDIX E: Amphibole analyses; Danburg gr. (DG, sch) & mafic enclaves (E)

	DG 202sch	DG 202sch	DG 202sch	DG 202sch	DG 202sch
			near core	near core	incl. in pl
SiO2	44.20	43.81	43.96	43.95	44.44
TiO2	0.98	0.82	0.73	1.18	1.41
Al2O3	8.24	8.95	8.87	8.81	8.55
Fe(t)(FeO)	17.55	17.13	17.45	16.90	14.41
MnO	0.65	0.88	0.69	0.70	0.63
MgO	11.09	11.05	11.27	11.46	12.84
CaO	11.47	11.42	11.65	11.44	11.82
Na2O	1.54	1.64	1.68	1.68	1.42
K2O	1.18	1.21	1.22	1.20	1.21
F	0.93	1.05	0.95	1.10	1.05
Cl	0.09	0.08	0.07	0.07	0.06
BaO	0.00	0.00	0.00	0.00	0.00
Sum(ox)	97.49	97.57	98.11	98.00	97.37
Formula					
calculations			23 O basis		
sum cats	15.745	15.781	15.818	15.778	15.709
Si	6.638	6.551	6.548	6.556	6.595
Ti	0.111	0.092	0.082	0.132	0.157
Al	1.459	1.577	1.557	1.549	1.495
Fe3+	0.724	0.896	0.850	0.742	0.693
Fe2+	1.481	1.246	1.324	1.366	1.095
Mn	0.083	0.111	0.087	0.088	0.079
Mg	2.483	2.463	2.502	2.548	2.840
Ca	1.846	1.830	1.859	1.828	1.879
Na	0.448	0.475	0.485	0.486	0.409
Κ	0.226	0.231	0.232	0.228	0.229
Ba	0.000	0.000	0.000	0.000	0.000
F	0.442	0.497	0.448	0.519	0.493
Cl	0.023	0.020	0.018	0.018	0.015
OH	1.535	1.483	1.535	1.463	1.492
ox+H2O	99.04	99.07	99.67	99.48	98.89
Fe3/Fe(t)	0.328	0.418	0.391	0.352	0.388
sum[vi+iv]	12.977	12.937	12.949	12.981	12.955
sum[vi]	4.977	4.937	4.949	4.981	4.955

APPENDIX E: Amphibole analyses; Danburg gr. (DG, sch) & mafic enclaves (E)

mane enclav	es (E)				
	DG 202sch	205 E	205 E	205 E	205 E
	incl. in pl	core	rim	rim	core
SiO2	44.35	43.61	43.87	43.70	43.88
TiO2	1.32	1.38	1.04	1.16	1.29
Al2O3	8.45	8.10	7.99	8.17	7.85
Fe(t)(FeO)	14.58	17.00	16.87	16.91	17.16
MnO	0.63	0.84	0.85	0.84	0.84
MgO	12.91	10.82	10.78	10.71	10.97
CaO	11.77	11.23	11.18	11.35	11.21
Na2O	1.51	1.65	1.69	1.56	1.65
K2O	1.24	1.18	1.16	1.15	1.20
F	1.02	0.95	0.76	1.01	0.85
Cl	0.06	0.13	0.10	0.12	0.11
BaO	0.00	0.00	0.06	0.07	0.00
Sum(ox)	97.39	96.44	95.99	96.28	96.61
Formula					
calculations			23 O basis		
sum cats	15.749	15.737	15.733	15.715	15.746
Si	6.597	6.644	6.686	6.649	6.678
Ti	0.148	0.158	0.119	0.133	0.148
Al	1.481	1.454	1.435	1.465	1.408
Fe3+	0.646	0.584	0.675	0.705	0.537
Fe2+	1.167	1.581	1.475	1.447	1.647
Mn	0.079	0.108	0.110	0.108	0.108
Mg	2.862	2.457	2.449	2.429	2.488
Ca	1.876	1.833	1.826	1.850	1.828
Na	0.435	0.487	0.499	0.460	0.487
Κ	0.235	0.229	0.226	0.223	0.233
Ba	0.000	0.000	0.004	0.004	0.000
F	0.480	0.458	0.366	0.486	0.409
Cl	0.015	0.034	0.026	0.031	0.028
OH	1.505	1.509	1.608	1.483	1.563
ox+H2O	98.92	97.94	97.58	97.75	98.16
Fe3/Fe(t)	0 356	0.270	0.314	0.328	0.246

sum[vi+iv]

sum[vi]

12.981

4.981

12.987

4.987

12.949

4.949

12.936

4.936

13.014

5.014

APPENDIX E: Amphibole analyses; Danburg gr. (DG, sch) & mafic enclaves (E)

eliciaves (E)					
	205 E	205 E	205 E	205 E	209 E
	rim	rim		rim	core
SiO2	43.00	43.43	43.77	43.41	44.10
TiO2	0.73	0.70	1.46	1.02	1.54
A12O3	8.79	8.50	8.00	8.09	8.34
Fe(t)(FeO)	18.01	18.05	17.27	17.21	17.20
MnO	0.84	0.71	0.74	0.72	0.71
MgO	10.35	10.19	10.90	10.67	10.89
CaO	11.22	11.19	11.26	11.37	11.29
Na2O	1.64	1.55	1.50	1.47	1.72
K2O	1.19	1.22	1.25	1.17	1.21
F	0.83	0.64	0.87	0.91	0.77
Cl	0.05	0.13	0.11	0.08	0.15
BaO	0.04	0.07	0.04	0.05	0.00
Sum(ox)	96.32	96.06	96.76	95.76	97.54
Formula					
calculations			23 O basis		
sum cats	15.803	15.751	15.720	15.728	15.730
Si	6.543	6.623	6.651	6.642	6.629
Ti	0.084	0.080	0.167	0.117	0.174
Al	1.576	1.528	1.433	1.459	1.478
Fe3+	0.891	0.820	0.556	0.728	0.598
Fe2+	1.401	1.482	1.639	1.475	1.564
Mn	0.108	0.092	0.095	0.093	0.090
Mg	2.347	2.316	2.469	2.434	2.440
Ca	1.829	1.828	1.833	1.864	1.818
Na	0.484	0.458	0.442	0.436	0.501
Κ	0.231	0.237	0.242	0.228	0.232
Ba	0.002	0.004	0.002	0.003	0.000
F	0.399	0.309	0.418	0.440	0.366
Cl	0.013	0.034	0.028	0.021	0.038
OH	1.588	1.658	1.554	1.539	1.596
ox+H2O	97.90	97.70	98.31	97.27	99.14
Fe3/Fe(t)	0.389	0.356	0.253	0.330	0.277

sum[vi+iv]

sum[vi]

12.951

4.951

12.942

4.942

13.010

5.010

12.948

4.948

12.974

4.974

APPENDE : Amphibole analyses; Danburg gr. (DG, sch) & mafic enclaves (E)

	209 E	209 E	209 E	209 E	209 E
	interior	rim	core	rim	rim
SiO2	43.89	43.36	43.96	44.18	44.51
TiO2	1.31	1.12	1.41	1.15	1.39
A12O3	8.17	8.51	8.45	8.47	8.21
Fe(t)(FeO)	17.81	18.41	18.00	18.11	17.28
MnO	0.72	0.66	0.68	0.53	0.61
MgO	10.69	10.67	10.41	10.63	11.03
CaO	11.33	11.38	11.42	11.58	11.61
Na2O	1.64	1.54	1.47	1.46	1.51
K2O	1.20	1.28	1.21	1.15	1.17
F	0.84	0.79	0.74	0.79	0.81
Cl	0.13	0.16	0.10	0.09	0.07
BaO	0.00	0.00	0.00	0.00	0.00
Sum(ox)	97.32	97.48	97.50	97.77	97.83
Formula					
calculations			23 O basis		
sum cats	15.748	15.798	15.697	15.709	15.694
Si	6.636	6.557	6.613	6.614	6.655
Ti	0.149	0.127	0.160	0.129	0.156
Al	1.456	1.517	1.498	1.494	1.447
Fe3+	0.600	0.688	0.702	0.771	0.642
Fe2+	1.652	1.640	1.563	1.496	1.519
Mn	0.092	0.085	0.087	0.067	0.077
Mg	2.409	2.405	2.334	2.372	2.458
Ca	1.836	1.844	1.841	1.857	1.860
Na	0.481	0.452	0.429	0.424	0.438
Κ	0.231	0.247	0.232	0.220	0.223
Ba	0.000	0.000	0.000	0.000	0.000
F	0.402	0.378	0.352	0.374	0.383
Cl	0.033	0.041	0.025	0.023	0.018
OH	1.565	1.581	1.622	1.603	1.599
ox+H2O	98.89	99.06	99.13	99.39	99.45
Fe3/Fe(t)	0.266	0.296	0.310	0.340	0.297
sum[vi+iv]	12.995	13.020	12.956	12.944	12.954
sum[vi]	4.995	5.020	4.956	4.944	4.954

APPENDE: Amphibole analyses; Danburg gr. (DG, sch) & mafic enclaves (E)

	209 E	209 E	207X	207X	207X
	rim	core	rim	interior	core
SiO2	44.13	44.26	43.23	44.22	44.15
TiO2	1.21	1.16	0.99	1.52	1.46
A12O3	8.54	8.25	8.82	8.18	8.09
Fe(t)(FeO)	18.30	17.67	17.36	17.41	16.94
MnO	0.74	0.60	0.84	0.87	0.81
MgO	10.62	10.94	10.67	11.24	11.27
CaO	11.38	11.60	11.60	11.57	11.53
Na2O	1.64	1.53	1.53	1.58	1.59
K2O	1.15	1.22	1.24	1.26	1.18
F	0.91	0.82	0.92	0.99	1.01
Cl	0.15	0.09	0.08	0.12	0.07
BaO	0.00	0.00	0.00	0.00	0.00
Sum(ox)	98.33	97.76	96.86	98.50	97.65
Formula					
calculations			23 O basis		
sum cats	15.749	15.736	15.779	15.758	15.736
Si	6.598	6.637	6.535	6.619	6.641
Ti	0.136	0.131	0.113	0.171	0.165
Al	1.505	1.458	1.571	1.443	1.434
Fe3+	0.709	0.676	0.835	0.507	0.541
Fe2+	1.579	1.540	1.359	1.673	1.590
Mn	0.094	0.076	0.108	0.110	0.103
Mg	2.367	2.445	2.404	2.508	2.527
Ca	1.823	1.864	1.879	1.855	1.858
Na	0.475	0.445	0.448	0.459	0.464
K	0.219	0.233	0.239	0.241	0.226
Ba	0.000	0.000	0.000	0.000	0.000
F	0.430	0.389	0.440	0.469	0.481
Cl	0.038	0.023	0.020	0.030	0.018
OH	1.532	1.588	1.540	1.501	1.502
ox+H2O	99.88	99.36	98.40	100.01	99.16
Fe3/Fe(t)	0.310	0.305	0.381	0.232	0.254
sum[vi+iv]	12.988	12.963	12.926	13.030	13.002
sum[vi]	4.988	4.963	4.926	5.030	5.002

APPENDE: Amphibole analyses; Danburg gr. (DG, sch) & mafic enclaves (E)

APPENDIX F: TITANITE MICROPROBE ANALYSES

und chicia ves	(L)				
Sample	DG 301	DG 301	DG 301	DG 301	DG 201
SiO2	30.32	29.78	29.38	29.48	29.70
A12O3	1.93	1.70	1.99	2.00	1.98
FeO	2.10	2.11	2.18	2.55	2.50
MgO	0.06	0.05	0.05	0.10	0.05
CaO	27.52	27.10	27.23	26.68	26.92
Na2O	0.03	0.02	0.04	0.06	0.02
K2O	•	•	•	•	•
TiO2	34.42	34.75	34.14	33.83	34.09
P2O5	•	•	•	•	•
MnO	0.21	0.19	0.20	0.22	0.21
F	0.91	0.79	0.85	0.81	0.89
Cr2O5	0.00	0.01	0.02	0.00	0.00
ZrO2	0.03	0.07	0.12	0.12	0.15
Nb2O5	0.19	0.23	0.14	0.39	0.34
BaO	•	•	•	•	•
<u>Ta2O5</u>	<u>0.12</u>	<u>0.08</u>	<u>0.06</u>	<u>0.01</u>	<u>0.25</u>
Totals	97.84	96.88	96.40	96.25	97.10
formula calcu	ulations	2	20 O basis		
Si	4.07	4.04	4.01	4.03	4.03
Al	.310	.270	.320	.320	.320
Fe2	.240	.240	.250	.290	.280
Mg	.010	.010	.010	.020	.010
Ca	3.96	3.94	3.98	3.91	3.92
Na	.010	.010	.010	.020	.010
Κ	•	•	•	•	•
Ti	3.47	3.54	3.50	3.48	3.48
Р	•	•	•	•	•
Mn	.020	.020	.020	.030	.020
F	.390	.340	.370	.350	.380
Zr	.000	.010	.010	.010	.010
Ba	•	•	•	•	•
Nb	.010	.010	.010	.020	.020
mg #	4.85	4.05	3.93	6.53	3.44
Total Cat	12.48	12.43	12.49	12.47	12.48

APPENDIX F: Titanite analyses, Danburg pluton (DG, sch) and enclaves (E)

(DO, 501) und					
Sample	DG 201	DG 201	DG D3	DG D3	DG D3
SiO2	29.60	29.74	29.33	30.07	30.95
Al2O3	1.87	2.06	1.94	1.84	1.74
FeO	2.28	2.41	2.53	1.85	1.77
MgO	0.06	0.05	0.05	0.01	0.02
CaO	26.77	27.12	27.03	27.95	26.51
Na2O	0.04	0.06	0.00	0.01	0.06
K2O	•	•	•	•	•
TiO2	34.12	33.66	33.83	34.67	33.91
P2O5	•	•	•	•	•
MnO	0.21	0.21	0.21	0.17	0.18
F	0.78	0.91	0.84	0.87	0.79
Cr2O5	0.00	0.00	0.00	0.06	0.00
ZrO2	0.09	0.09	0.19	0.07	0.02
Nb2O5	0.24	0.19	0.24	0.31	0.21
BaO	•	•	•	•	•
<u>Ta2O5</u>	<u>0.06</u>	<u>0.03</u>	<u>0.01</u>	<u>0.00</u>	<u>0.10</u>
Totals	96.12	96.53	96.20	97.88	96.26
formula		2	0 O basis		
calculations					
Si	4.05	4.05	4.02	4.04	4.19
Al	.300	.330	.310	.290	.278
Fe2	.260	.270	.290	.210	.201
Mg	.010	.010	.010	.000	.004
Ca	3.92	3.96	3.97	4.02	3.85
Na	.010	.020	.000	.000	.016
Κ	•	•	•	•	•
Ti	3.51	3.45	3.48	3.50	3.46
Р	•	•	•	•	•
Mn	.020	.020	.020	.020	.021
F	.340	.390	.360	.370	.339
Zr	.010	.010	.010	.010	.001
Ba	•	•	•	•	•
Nb	.020	.010	.020	.020	.013
mg #	4.48	3.57	3.40	0.95	1.97
Total Cat	12.44	12.52	12.49	12.47	12.37

APPENDIX F: Titanite analyses, Danburg pluton (DG, sch) and enclaves (E)

(DO, SOI) and					
Sample	DG D3	DG D3	D1	DG 201	D1
SiO2	30.53	30.22	28.86	30.95	30.53
A12O3	2.19	1.85	1.58	1.74	2.19
FeO	2.08	2.22	2.18	1.77	2.08
MgO	0.05	0.07	0.04	0.02	0.05
CaO	25.88	25.73	26.80	26.51	25.88
Na2O	0.06	0.07	0.10	0.06	0.06
K2O	•	•	0.00	•	•
TiO2	32.98	33.42	35.04	33.91	32.98
P2O5	•	•	0.08	•	•
MnO	0.25	0.24	0.19	0.18	0.25
F	1.01	0.85	0.83	0.79	1.01
Cr2O5	0.00	0.00	•	0.00	0.00
ZrO2	0.02	0.15	0.09	0.02	0.02
Nb2O5	0.14	0.29	•	0.21	0.14
BaO	•	•	0.19	•	•
<u>Ta2O5</u>	<u>0.00</u>	<u>0.01</u>	<u>•</u>	<u>0.10</u>	0.00
Totals	95.19	95.12	95.98	96.26	95.19
formula		20) O basis		
calculations					
Si	4.18	4.15	3.96	4.19	4.18
Al	.353	.300	.256	0.278	0.353
Fe2	.238	.255	.250	0.201	0.238
Mg	.010	.014	.008	0.004	0.01
Ca	3.80	3.79	3.94	3.85	3.8
Na	.016	.019	.027	0.016	0.016
Κ	•	•	.000	•	•
Ti	3.40	3.45	3.62	3.46	3.4
Р	•	•	.009	•	•
Mn	.029	.028	.022	0.021	0.029
F	.437	.369	.360	0.339	0.437
Zr	.001	.010	.006	0.001	0.001
Ba	•	•	.010	•	•
Nb	.009	.018	•	0.013	0.009
mg #	4.11	5.32	3.17	1.97	4.11
Total Cat	12.46	12.40	12.46	12.37	12.46

APPENDIX F: Titanite analyses, Danburg pluton (DG, sch) and enclaves (E)

(,		· /			
Sample	D1	DG202sch	DG202sch	DG202sch	DG202sch
SiO2	30.22	28.47	28.74	29.72	29.47
Al2O3	1.85	1.58	1.65	1.94	1.93
FeO	2.22	2.05	1.82	1.86	2.37
MgO	0.07	0.05	0.05	0.03	0.04
CaO	25.73	26.36	26.4	28.23	27.56
Na2O	0.07	0.05	0.04	0.02	0.09
K2O	•	0	0	0	0.01
TiO2	33.42	34.55	34.56	34.94	35.22
P2O5	•	0.09	0.1	0	0.06
MnO	0.24	0.17	0.22	0.15	0.17
F	0.85	0.71	0.76	1.21	1.08
Cr2O5	0.00	•	•	•	•
ZrO2	0.15	0.09	0.06	0.05	0.03
Nb2O5	0.29	•	•	•	•
BaO	•	0.19	0.22	0.2	0.21
<u>Ta2O5</u>	<u>0.01</u>	<u>•</u>	<u>•</u>	<u>•</u>	<u>•</u>
Totals	95.12	94.36	94.62	98.35	98.24
formula			20 O basis		
calculations					
Si	4.15	3.97	3.99	3.98	3.95
Al	0.3	0.260	0.270	0.306	0.305
Fe2	0.255	0.239	0.211	0.208	0.266
Mg	0.014	0.010	0.010	0.006	0.008
Ca	3.79	3.94	3.93	4.05	3.96
Na	0.019	0.014	0.011	0.005	0.023
Κ	•	0.000	0.000	0.000	0.002
Ti	3.45	3.62	3.61	3.52	3.55
Р	•	0.011	0.012	0.000	0.007
Mn	0.028	0.020	0.026	0.017	0.019
F	0.369	0.313	0.334	0.512	0.458
Zr	0.01	0.006	0.004	0.003	0.002
Ba	•	0.01	0.012	0.01	0.011
Nb	0.018	•	•	•	•
mg #	5.32	4.17	4.67	2.80	2.92
Total Cat	12.4	12.41	12.41	12.61	12.56

APPENDIX F: Titanite analyses, Danburg pluton (DG, sch) and enclaves (E)

(DO, SOI) al					
Sample	DG202sch	207 E	207 E	207 E	207 E
SiO2	28.97	29.96	29.61	29.90	30.00
Al2O3	1.96	1.85	2.05	1.62	1.61
FeO	2.27	1.98	2.50	1.74	1.88
MgO	0.07	0.05	0.03	0.02	0.03
CaO	26.85	27.56	27.75	27.19	27.15
Na2O	0	0.06	0.01	0.05	0.03
K2O	0	•	•	•	•
TiO2	34.23	34.73	34.57	35.40	35.29
P2O5	0.1	•	•	•	•
MnO	0.13	0.30	0.21	0.23	0.24
F	1.05	0.73	0.83	0.53	0.60
Cr2O5	•	0.00	0.00	0.00	0.00
ZrO2	0.13	0.05	0.05	0.19	0.02
Nb2O5	•	0.17	0.22	0.31	0.21
BaO	0.18	•	•	•	•
<u>Ta2O5</u>	<u>•</u>	0.00	<u>0.05</u>	<u>0.04</u>	0.00
Totals	95.94	97.44	97.88	97.22	97.06
formula		20) O basis		
calculations					
Si	3.97	4.04	3.99	4.04	4.05
Al	0.317	.290	.330	.260	.260
Fe2	0.260	.220	.280	.200	.210
Mg	0.014	.010	.010	.000	.010
Ca	3.95	3.98	4.00	3.93	3.93
Na	0.000	.020	.000	.010	.010
Κ	0.000	•	•	•	•
Ti	3.53	3.52	3.50	3.59	3.59
Р	0.012	•	•	•	•
Mn	0.015	.030	.020	.030	.030
F	0.455	.310	.350	.230	.260
Zr	0.009	.000	.000	.010	.000
Ba	0.01	•	•	•	•
Nb	•	.010	.010	.020	.010
mg #	5.21	4.31	2.09	2.01	2.77
Total Cat	12.53	12.44	12.50	12.32	12.35

APPENDIX F: Titanite analyses, Danburg pluton	
(DC, sah) and analouss (E)	

(DO, SOI) and V						
Sample	207 E					
SiO2	30.42	29.69	29.72	29.95	30.11	
A12O3	1.97	1.77	1.73	1.66	1.72	
FeO	2.26	1.86	2.07	1.96	1.82	
MgO	0.06	0.03	0.06	0.04	0.03	
CaO	27.68	27.19	27.22	27.44	27.72	
Na2O	0.02	0.03	0.00	0.03	0.03	
K2O	•	•	•	•	•	
TiO2	34.43	34.70	34.35	34.85	34.97	
P2O5	•	•	•	•	•	
MnO	0.16	0.19	0.21	0.07	0.22	
F	0.74	0.67	0.76	0.70	0.73	
Cr2O5	0.00	0.00	0.03	0.00	0.00	
ZrO2	0.04	0.05	0.10	0.11	0.08	
Nb2O5	0.17	0.26	0.35	0.20	0.23	
BaO	•	•	•	•	•	
<u>Ta2O5</u>	<u>0.34</u>	<u>0.00</u>	<u>0.00</u>	<u>0.00</u>	<u>0.17</u> □	
Totals	98.29	96.44	96.60	97.01	97.66	
formula	20 O basis					
calculations						
Si	4.08	4.04	4.04	4.05	4.05	
Al	.310	.280	.280	.270	.270	
Fe2	.250	.210	.240	.220	.210	
Mg	.010	.010	.010	.010	.010	
Ca	3.97	3.96	3.97	3.98	3.99	
Na	.010	.010	.000	.010	.010	
Κ	•	•	•	•	•	
Ti	3.47	3.55	3.51	3.55	3.53	
Р	•	•	•	•	•	
Mn	.020	.020	.020	.010	.030	
F	.310	.290	.330	.300	.310	
Zr	.000	.000	.010	.010	.010	
Ba	•	•	•	•	•	
Nb	.010	.020	.020	.010	.010	
mg #	4.52	2.8	4.91	3.51	2.85	
Total Cat	12.44	12.39	12.43	12.40	12.42	

APPENDIX F: Titanite analyses, Danburg pluton (DG, sch) and enclaves (E)

Sample	101 E	101 E	101 E	101 E	309 E	
SiO2	28.75	28.97	29.39	29.38	30.90	
A12O3	1.96	2.14	1.79	1.93	1.90	
FeO	2.39	1.91	1.96	1.88	1.98	
MgO	0.06	0.07	0.08	0.06	0.05	
CaO	26.78	27.00	27.81	27.75	27.32	
Na2O	0.00	0.00	0.00	0.03	0.04	
K2O	0.04	0.00	0.00	0.00	•	
TiO2	33.96	34.12	35.58	34.87	34.28	
P2O5	0.09	0.03	0.06	0.03	•	
MnO	0.15	0.15	0.15	0.14	0.25	
F	1.01	1.19	1.08	1.21	0.85	
Cr2O5	•	•	•	•	0.01	
ZrO2	0.09	0.13	0.06	0.12	0.03	
Nb2O5	•	•	•	•	0.23	
BaO	0.18	0.16	0.16	0.19	•	
<u>Ta2O5</u>	<u>•</u>	<u>•</u>	<u>•</u>	<u>•</u>	0.00	
Totals	95.46	95.87	98.12	97.59	97.84	
formula	20 O basis					
calculations						
Si	3.97	3.97	3.94	3.96	4.13	
Al	.319	.346	.283	.307	0.299	
Fe2	.276	.219	.220	.212	0.221	
Mg	.012	.014	.016	.012	0.01	
Ca	3.96	3.97	4.00	4.01	3.91	
Na	.000	.000	.000	.008	0.01	
Κ	.007	.000	.000	.000	•	
Ti	3.52	3.52	3.59	3.54	3.45	
Р	.011	.003	.007	.003	•	
Mn	.018	.017	.017	.016	0.028	
F	.441	.516	.458	.516	0.359	
Zr	.006	.009	.004	.008	0.002	
Ba	.010	.009	.008	.010	•	
Nb	•	•	•	•	0.014	
mg #	4.283	6.132	6.782	5.383	4.31	
Total Cat	12.54	12.58	12.54	12.60	12.44	

APPENDIX F: Titanite analyses, Danburg pluton (DG, sch) and enclaves (E)

(DO, SOI) and V							
Sample	309 E	309 E	309 E	309 E	309 E		
SiO2	30.26	30.51	30.86	30.74	30.40		
Al2O3	1.95	2.00	1.90	2.44	2.07		
FeO	2.14	2.32	1.80	1.84	2.40		
MgO	0.04	0.06	0.02	0.03	0.05		
CaO	26.95	27.01	27.01	27.20	26.07		
Na2O	0.03	0.03	0.03	0.00	0.03		
K2O	•	•	•	•	•		
TiO2	34.51	33.58	34.26	33.49	33.08		
P2O5	•	•	•	•	•		
MnO	0.22	0.17	0.18	0.18	0.26		
F	0.85	0.97	0.86	1.22	0.90		
Cr2O5	0.00	0.00	0.06	0.00	0.05		
ZrO2	0.04	0.13	0.07	0.06	0.11		
Nb2O5	0.22	0.19	0.22	0.19	0.15		
BaO	•	•	•	•	•		
<u>Ta2O5</u>	<u>0.00</u>	<u>0.05</u>	0.09	<u>0.03</u>	<u>0.00</u>		
Totals	97.21	97.02	97.36	97.42	95.57		
formula	20 O basis						
calculations							
Si	4.08	4.12	4.14	4.12	4.16		
Al	0.31	0.318	0.301	0.385	0.334		
Fe2	0.241	0.262	0.202	0.206	0.275		
Mg	0.008	0.012	0.004	0.006	0.01		
Ca	3.89	3.91	3.89	3.91	3.82		
Na	0.008	0.008	0.008	0	0.008		
Κ	•	•	•	•	•		
Ti	3.5	3.41	3.46	3.38	3.4		
Р	•	•	•	•	•		
Mn	0.025	0.019	0.02	0.02	0.03		
F	0.362	0.414	0.365	0.517	0.389		
Zr	0.003	0.009	0.005	0.004	0.007		
Ba	•	•	•	•	•		
Nb	0.013	0.012	0.013	0.012	0.009		
mg #	3.23	4.41	1.94	2.82	3.58		
Total Cat	12.43	12.49	12.41	12.55	12.45		

APPENDIX F: Titanite analyses, Danburg pluton (DG, sch) and enclaves (E)

Sample	309 E	105 E	105 E	105 E	105 E	
SiO2	30.28	30.53	31.09	30.50	30.43	
Al2O3	2.05	2.13	2.47	1.98	2.15	
FeO	2.53	2.47	2.40	2.57	1.79	
MgO	0.05	0.07	0.03	0.06	0.04	
CaO	26.10	26.55	27.16	26.27	28.55	
Na2O	0.02	0.02	0.00	0.04	0.03	
K2O	•	•	•	•	•	
TiO2	33.17	32.87	32.81	32.96	34.85	
P2O5	•	•	•	•	•	
MnO	0.20	0.26	0.18	0.22	0.16	
F	1.05	1.01	1.34	0.92	0.93	
Cr2O5	0.00	0.12	0.00	0.00	0.09	
ZrO2	0.11	0.01	0.13	0.09	0.00	
Nb2O5	0.17	0.12	0.12	0.24	0.23	
BaO	•	•	•	•	•	
<u>Ta2O5</u>	<u>0.27</u>	0.21	0.00	0.00	0.01	
Totals	96.00	96.37	97.73	95.85	99.26	
formula	20 O basis					
calculations						
Si	4.14	4.16	4.16	4.16	4.03	
Al	0.33	0.342	0.389	0.319	.340	
Fe2	0.289	0.281	0.268	0.293	.200	
Mg	0.01	0.014	0.006	0.012	.010	
Ca	3.82	3.87	3.89	3.84	4.05	
Na	0.005	0.005	0	0.011	.010	
Κ	•	•	•	•	•	
Ti	3.41	3.37	3.3	3.38	3.47	
Р	•	•	•	•	•	
Mn	0.023	0.03	0.02	0.025	.020	
F	0.454	0.435	0.567	0.397	.390	
Zr	0.007	0.001	0.008	0.006	.000	
Ba	•	•	•	•	•	
Nb	0.011	0.007	0.007	0.015	.010	
mg #	3.4	4.81	2.18	4	3.83	
Total Cat	12.5	12.51	12.61	12.47	12.51	

APPENDIX F: Titanite analyses, Danburg pluton (DG, sch) and enclaves (E)

Sample	105 E	105 E	
SiO2	29.53	29.16	
A12O3	1.58	1.57	
FeO	1.97	2.26	
MgO	0.05	0.06	
CaO	26.65	26.44	
Na2O	0.01	0.06	
K2O	•	•	
TiO2	34.89	34.71	
P2O5	•	•	
MnO	0.14	0.19	
F	0.62	0.55	
Cr2O5	0.00	0.00	
ZrO2	0.12	0.18	
Nb2O5	0.40	0.40	
BaO	•	•	
<u>Ta2O5</u>	0.23	0.06	
Totals	96.19	95.64	
formula	20 O basis		
calculations			
Si	4.04	4.01	
Al	.260	.260	
Fe2	.230	.260	
Mg	.010	.010	
Ca	3.90	3.90	
Na	.000	.020	
Κ	•	•	
Ti	3.59	3.59	
Р	•	•	
Mn	.020	.020	
F	.270	.240	
Zr	.010	.010	
Ba	•	•	
Nh		0.20	
IND	.030	.030	
mg #	.030 4.33	.030 4.52	

APPENDIX F: Titanite analyses, Danburg pluton (DG, sch) and enclaves (E)